Acute Poliomyelitis

LUMLEIAN LECTURES

1916

BATTEN

ACUTE POLIOMYELITIS

ITS NATURE AND TREATMENT

BEING THE LUMLEIAN LECTURES DELIVERED AT THE ROYAL COLLEGE OF PHYSICIANS LONDON, 1916

BY

FREDERICK E. BATTEN, M.D.CANTAB., F.R.C.P.

Physician to the National Hospital for the Paralysed and Epileptic, Queen Square; Physician to the Hospital for Sick Children, Great Ormond Street; Membre Correspondant de la Société de Neurologie de Paris; Corresponding Member of the Philadelphia Neurological Society

[Reprinted from "Brain," Vol. xxxix, 1916]

LONDON

JOHN BALE, SONS & DANIELSSON, LTD.

OXFORD HOUSE

83-91, GREAT TITCHFIELD STREET, OXFORD STREET, W.

1916

ACUTE POLIOMYELITIS.

Chapter I.—Introduction.

Mr. President and Fellows,—I would in the first place wish to thank the College for the honour they have conferred on me by their invitation to deliver the Lumleian Lectures for 1916.

The subject, acute poliomyelitis, is one which has not previously been dealt with by a Lumleian Lecturer, although a consideration of some points formed part of Farquhar Buzzard's Goulstonian Lectures, delivered in 1907 [33].

Since that date not only has poliomyelitis spread in epidemic form over the face of the globe, but considerable advances have been made in our knowledge of the disease. It is true that previous to 1905 small epidemics had occurred, but it is only since that date that it has had its present wide prevalence.

During the last six years the experimental investigation of Flexner and his co-workers at the Rockefeller Institute, of Levaditi at the Pasteur Institute, and Leiner and von Wiesner in Austria, and Römer in Marburg, have thrown much light on the nature of the disease.

A wider knowledge of the clinical manifestations has been gained, and the investigation of acute cases has rendered the pathological process more clear.

It is my purpose to put before you in these Lumleian Lectures the epidemiological, experimental, and clinical observations, and some points with regard to treatment of the acute stage of the disease.

It is during the last five years that poliomyelitis has been recognized by the Public Health authorities in England as a definite specific fever, and notification has been adopted. The British Islands have suffered comparatively little during the epidemic period.

Although much has been discovered with regard to its nature, it has not yet been possible to apply that knowledge to its prevention, and much investigation still remains to be done, not only in the experimental, but also in the clinical and epidemiological fields.

The likeness which the disease bears to rabies has raised the hope that precautions, which have been so successful in dealing with that infection, might be able to control poliomyelitis, but in its spread it bears such a likeness to that of meningococcal meningitis that this can hardly be expected. It seems unlikely, however, that any effectual remedy, other than prevention, will be found for a disease which is so fulminating in attack and so destructive in its effects on the central nervous system.

The first lecture will be devoted to the epidemiology and pathology ; the second to the experimental side, and the third to the clinical consideration of the subject.

The names which have been used and suggested for the disease are numerous: spinal infantile paralysis, epidemic infantile paralysis, epidemic poliomyelitis, meningo-myelo-encephalitis disseminata, polio-encephalo-myelitis, Heine-Medinische Krankheit, acute anterior poliomyelitis, and acute poliomyelitis.

There is no doubt that the terms meningo-myelo-encephalitis disseminata and polio-encephalo-myelitis most accurately describe the anatomical and pathological changes; but the name "acute poliomyelitis" has now come into such general clinical use, and is used to describe the nature of the virus, that it is inadvisable to attempt to replace it. All that is required is that poliomyelitis shall be recognized as one of the acute specific fevers, having a tendency to affect any part of the central nervous system, and giving rise to a variety of symptoms dependent on the portion affected.

Epidemiology of Poliomyelitis.

(1) *Historical.*

The history of the earlier epidemics of poliomyelitis has been written by Allen Starr [26], Holt and Bartlett [12], who collected the records of thirty-five epidemics of poliomyelitis up till 1907, and further details were reported in the papers of Wickman [27], Job and Froment [14], and Sever [25].

In 1911 I collected additional records of some twenty-six epidemics in all parts of the world, and these, together with those previous to 1907, are recorded in a paper on the subject published in Brain of that year [1].

(2) *World-spread.*

The leading features of the past epidemics may, however, be shortly stated. The first record of the disease in an epidemic form came from Sweden in 1881. In 1883 some groups of cases were recorded in Italy, and in 1886 in Norway, Germany, and France. All these epidemics were small in numbers. In 1887, Medin described an epidemic in Stockholm of forty-four cases, and this is the first important work on the subject. In 1894 an epidemic of 132 cases occurred in Rutland, Massachusetts, which was recorded by Caverly and McPhail. Small epidemics were recorded in the "nineties" in Italy, France, Australia,

England and America, and a larger one occurred in Vienna (forty-two cases) in 1898, and in Norway and Sweden in 1899. This last was described by Wickman, to whom so much is due in regard to the investigation of the pathology and the spread of the disease. In the middle of the next decade—viz., 1900 to 1910—the record of cases, which before had been limited to two figures, now reached to four figures, and during the years 1903-07 it may be said that the disease was pandemic in Norway and Sweden. During the years 1907-10 large epidemics occurred in the States of New York and of Massachusetts. At the same time epidemics of the disease were recorded in Australia (Stephens), in Vienna (Zappert), Westphalia (Krause and Reckzek), in Paris (Netter), in Austria (Furnratt, Potpeschnigg, Lindner and Mally), Switzerland (Hagenback), and in Russia (Jogichess).

During the year 1910 the total number of cases and deaths from poliomyelitis in the United States was 5,093 and 825 respectively, a mortality of about 13·75 per cent. The epidemics in Massachusetts in 1909 and 1910 were most carefully investigated by Lovett [17] and his co-workers, and in Cincinnati and Batavia in 1911 and 1912 by Wade Frost [9], in regard to all the following factors: rainfall, temperature, surroundings, nearness to railroad, nearness to water, age of house, sanitary conditions, location of house, character of house, floor of house inhabited by a family, sewage disposal, character of water supply, relation to dust, prevalence of vermin, insects and rodents, data as to domestic animals kept, occurrence of paralysis in animals, swimming and wading, exposure to heat, cold or damp, diet, and attendance at school. No common factor could be found. No relation to dust, prevalence of vermin, or the keeping of domestic animals could be ascertained, and the same is true of the numerous other points investigated.

(3) *Factors common to all Epidemics of Poliomyelitis.*

There are, however, certain factors common to all epidemics, and these may be shortly stated.

Seasonal relationship.—In the Northern Hemisphere the disease always has the greatest prevalence during the months of July, August, September and October, the months of August and September being nearly always those in which the greatest number of cases occurs. In the Southern Hemisphere the disease has occurred during the months of March and April—i.e., months which, I believe, in atmospheric conditions correspond fairly well to September and October

in the Northern Hemisphere. The disease was supposed not to occur in the Tropics, but an epidemic was reported in Cuba in 1909 by Lebredo and Recio [16], the maximum number of cases occurring in July and August, and in the island of Nauru, in the Southern Pacific, in January, 1909, by Müller [20]. It is interesting in the latter epidemic to note that it affected the natives of the island very severely. In this island, which has a population of 1,250 natives and 1,000 imported labourers (partly Chinese and partly Caroline Islanders) and about 80 whites, there were 700 cases of the disease: of these 38 died; 470 of the 700 cases occurred in natives of the island, and of these 37 died. The Chinese were unaffected, and only three Europeans were attacked. So the disease fell with peculiar severity on the native population and the imported Caroline Islanders.

Age-incidence.—The incidence of the disease on young children is a constant feature, and it commonly attacks these during the second and third years of life. Babies in arms are rarely affected, and as the age advances the incidence rapidly declines.

Mortality.—The mortality in the various epidemics varies considerably; over the total number of cases it amounts to from 11 to 12 per cent. Of the notified cases in England during the years 1912-13-14, the mortality was 13 per cent., 14 per cent. and 16·6 per cent. respectively; but this hardly represents the true mortality, which is probably considerably lower, for it is certain that many of the milder and abortive cases are not notified.

Incubation.—In the Swedish epidemic of 1905 (Wickman) the incubation period was shown to lie between one and four days, seventy-four of the 127 cases coming within this period. Currie and Bramwell [8] brought forward some very good evidence from a small localized epidemic in Tillicoultry that it was four days or less. There are some striking individual cases of isolated contact which show that the incubation may be as short as twelve hours.

Spread of infection.—Wickman showed that the disease spread by means of carriers along the lines of communication—road, railways, &c. He brought forward evidence of the spread of infection from school. The school epidemic reported by Wickman occurred in Trästena, a little village of 102 houses, of which nineteen were affected. The school was infected by a child attending on June 28, and a series of cases which could directly or indirectly be traced to the school occurred on July 3, July 4, July 8, July 10, and July 12. The school was shut on July 15. Other cases occurred during the month, and the last on August 4.

In this little parish of Trästena, with 500 inhabitants, forty-nine persons were affected, twenty-three with the abortive form of the disease, twenty-six with the paralytic form. Of the cases with paralysis, eleven died—i.e., 42·3 per cent. Three other instances of a school being a source of infection are given by Wickman. The disease appears always to be carried by contact, but the "carrier" may be a perfectly sound and healthy individual. Further evidence on school infection was collected by myself in 1911, but although isolated cases of poliomyelitis occasionally occurred in schools in England, yet no evidence of spread from this source was forthcoming [2].

The disease rarely occurs or spreads in institutions. An investigation in America of forty-five institutions in which 3,600 children resided, showed that only one child contracted the disease during an epidemic period.

(4) *Poliomyelitis as an Epidemic Disease in Great Britain.*

So far as I know, there is no record of any epidemic of poliomyelitis in England before 1897, when W. Pasteur [21] described the affection in seven members of one family. That record has become historic, as it is the highest number of members affected in the same family.

Thomas Buzzard [6], in 1898, published a lecture "On Cases illustrating the Infective Origin of Infantile Paralysis." He gives an instance of two sisters residing in the same house who were attacked with paralysis within six days of each other. Four other children of the same family escaped. Two other children living in a neighbouring street were taken ill in a similar way in the same week. He also mentions a case, seen in 1895, of a brother and sister who were taken ill within two days of one another; the sister was feverish and recovered without paralytic symptoms, the brother was paralysed in the left arm. These two cases are alluded to in Buzzard's Presidential Address before the Clinical Society in 1895.

It has, of course, long been recognized that poliomyelitis is prevalent during the summer months in London, and especially during August and September. I recorded an undue prevalence in 1904.

In 1908 Treves reported an epidemic of eight cases at Upminster, a small village in Essex.

In 1909 an epidemic of thirty-seven cases was reported by George Parker in Bristol.

In 1910 Garrow reported cases of poliomyelitis in Cumberland, notably in Carlisle and Barrow-in-Furness.

Dr. Beard, the Medical Officer of Health in Carlisle, recognizing that the disease was occurring in an epidemic form, obtained the sanction of the Health Committee to make the disease notifiable.

NUMBER OF CASES OF POLIOMYELITIS IN ENGLAND AND WALES FOR THE YEAR 1912.

FIG. 1.—The figures indicate the number of cases of poliomyelitis notified in each county during the year 1912.

This, I believe, was the first place in which notification was instituted in this country. In this year epidemics also occurred at Melton Mowbray, Cerne Abbas [1] and around Edinburgh [18].

In 1911 numerous epidemics were recorded throughout England; notably in Devon and Cornwall and in the Eastern Counties [4]. That in Devon and Cornwall was carefully investigated by Dr. Reece [23], the Inspector of the Local Government Board, but no definite conclusion was arrived at as to the mode of spread of the infection.

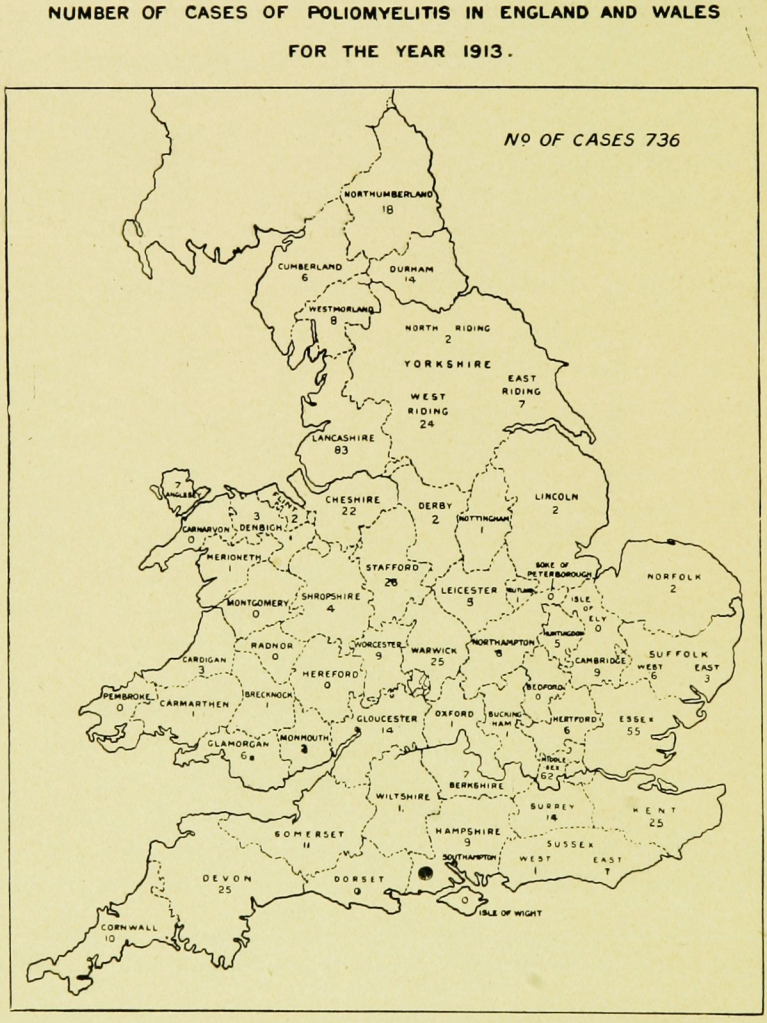


FIG. 2.—The figures indicate the number of cases of poliomyelitis notified in each county during the year 1913.

(5) *Distribution of Cases of Poliomyelitis in England for the Years 1912, 1913, 1914 and 1915.*

The study of the notified cases of poliomyelitis in England during the years 1912, 1913, 1914 and 1915 shows that the disease is distributed in a very irregular manner (figs. 1 to 4).

NUMBER OF CASES OF POLIOMYELITIS IN ENGLAND AND WALES FOR THE YEAR 1914.

FIG. 3.—The figures indicate the number of cases of poliomyelitis notified in each county during the year 1914.

Lancashire provided the largest number of cases: 192, 83, 80, for 1912, 1913, and 1914, but only 6 in 1915. A marked prevalence in

the same years is to be noted in the contiguous counties of Cheshire, Staffordshire and Warwickshire, and with the same sharp decline in 1915. Northamptonshire, Bedfordshire and Buckinghamshire, severely attacked in 1912, have remained fairly free since.

NUMBER OF CASES OF POLIOMYELITIS IN ENGLAND AND WALES FOR THE YEAR 1915.

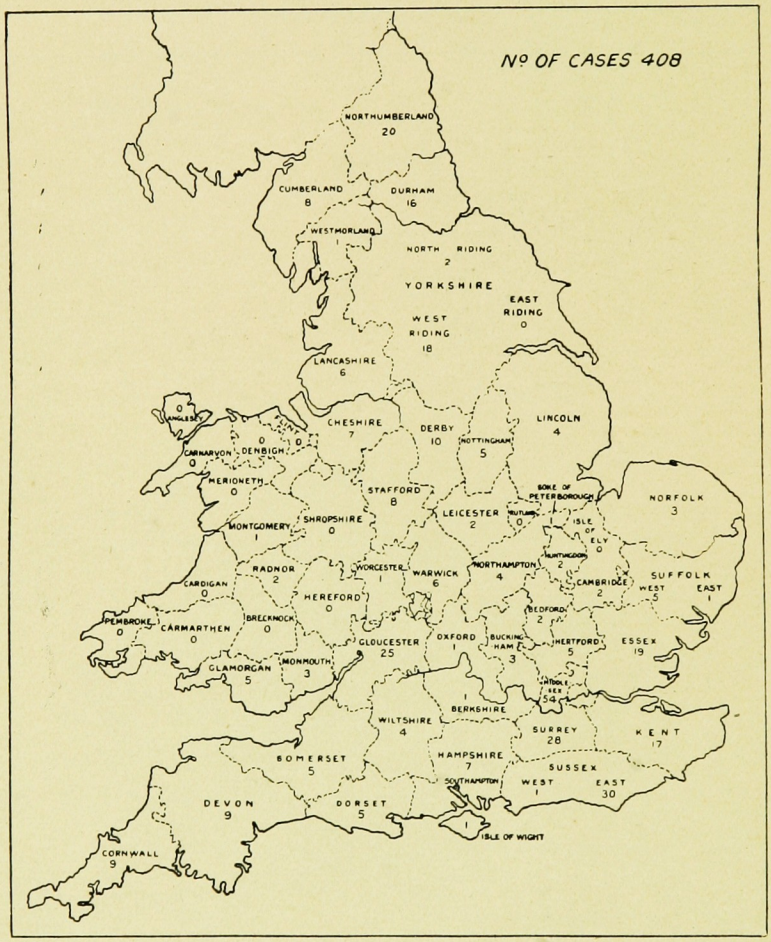


FIG. 4.—The figures indicate the number of cases of poliomyelitis notified in each county during the year 1915.

Gloucester had a high incidence in 1915, as had also East Sussex, neither of these counties being severely affected in the previous years.

The study of these maps suggests that poliomyelitis is, in its

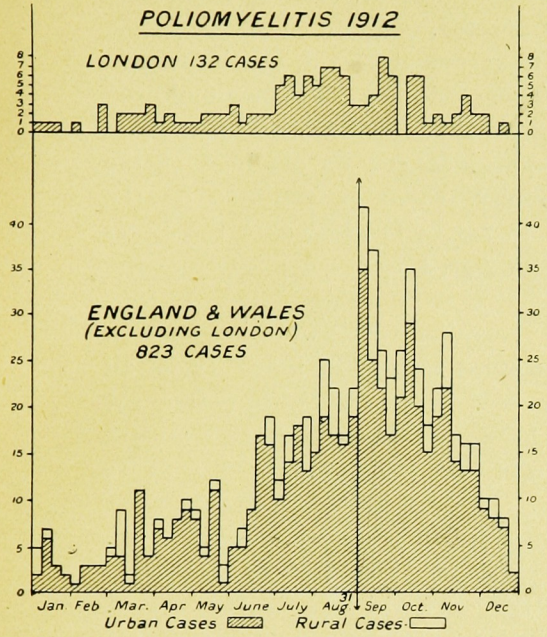
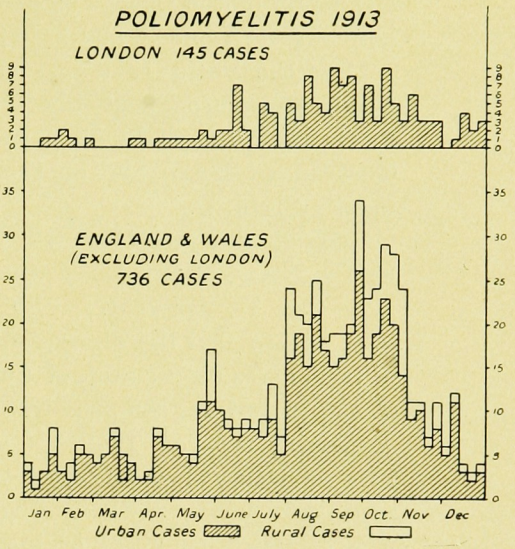


FIG. 5.



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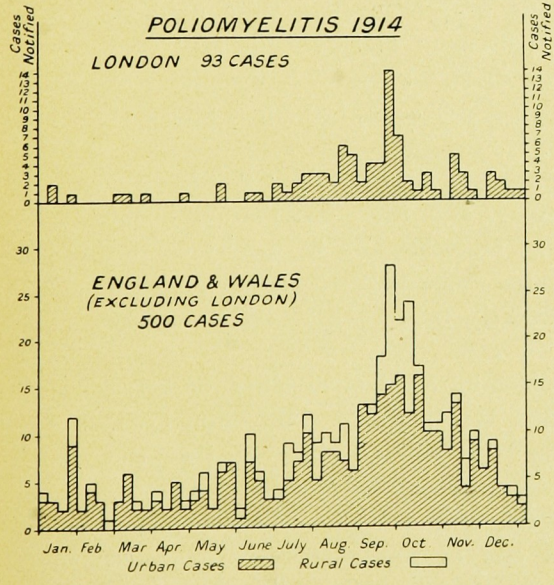


FIG. 7.

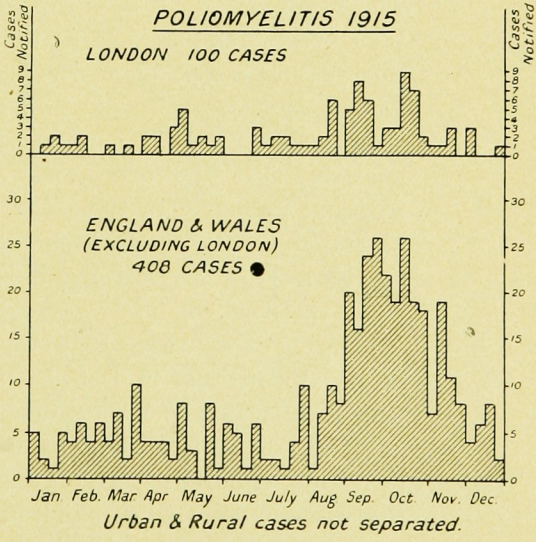


FIG. 8.

distribution, similar to meningococcal meningitis, only a very small percentage of the population being affected.

In September, 1911, the Local Government Board, on the recommendation of the College of Physicians, made the disease compulsorily notifiable for London, and in September, 1912, for the whole country.

For the years 1912-13-14-15 some idea can be obtained of the distribution throughout the community. This is indicated on the charts (figs. 5 to 8) kindly supplied to me by Dr. Reece, of the Local Government Board, and on the maps (figs. 1 to 4) compiled from the monthly returns.

During the year 1912, 823 cases of poliomyelitis were investigated by Dr. Reece, of the Local Government Board. The mortality for all ages was 13 per cent.; 51·9 per cent. recovered with permanent paralysis, so that the disease either killed or incapacitated to a greater or less degree 65 per cent. of those who were attacked, leaving a figure of 35 per cent. for complete recovery.

During the year 1913, 736 cases of poliomyelitis were investigated. The mortality for all ages was 14·4 per cent.; 53·6 per cent. recovered with permanent paralysis and 14·4 per cent. died. The disease thus killed or incapacitated in a greater or less degree 68 per cent. of those attacked. These figures would leave a figure of 32 per cent. for complete recovery.

During the year 1914, 500 cases of poliomyelitis were notified. The mortality for all ages was 16·6 per cent.; 47·7 per cent. recovered with permanent paralysis, so that the disease killed or incapacitated in this year to a greater or less degree 64 per cent., leaving a figure of 36 per cent. for complete recovery.

For the year 1915 complete figures are not available; it is known, however, that 408 cases were notified, and their distribution about England is shown in the map. The mortality and incapacity cannot be stated, but the figures for the three years 1912-13-14 having been 65, 68 and 64 respectively, it is unlikely that 1915 would show any great variation.

During the year 1913 an epidemic of poliomyelitis occurred in certain districts in Lancashire and Westmorland. Macewen [19], who investigated the epidemic, says: "It will be observed that the outbreak of poliomyelitis in Barrow was marked by its restriction to young children. The reason for this exceptional incidence of the disease on young children is one of the problems connected with poliomyelitis which still seem to need elucidation."

It is indeed a striking fact that of the nineteen cases specially investigated in Barrow, only two were over the age of 3 years, Nos. 1 and 16, aged 4 and 5 years respectively, occurring in groups 1 and 2 as indicated on the map (fig. 9). Now it is well known that Barrow suffered from a severe epidemic of poliomyelitis, investigated by

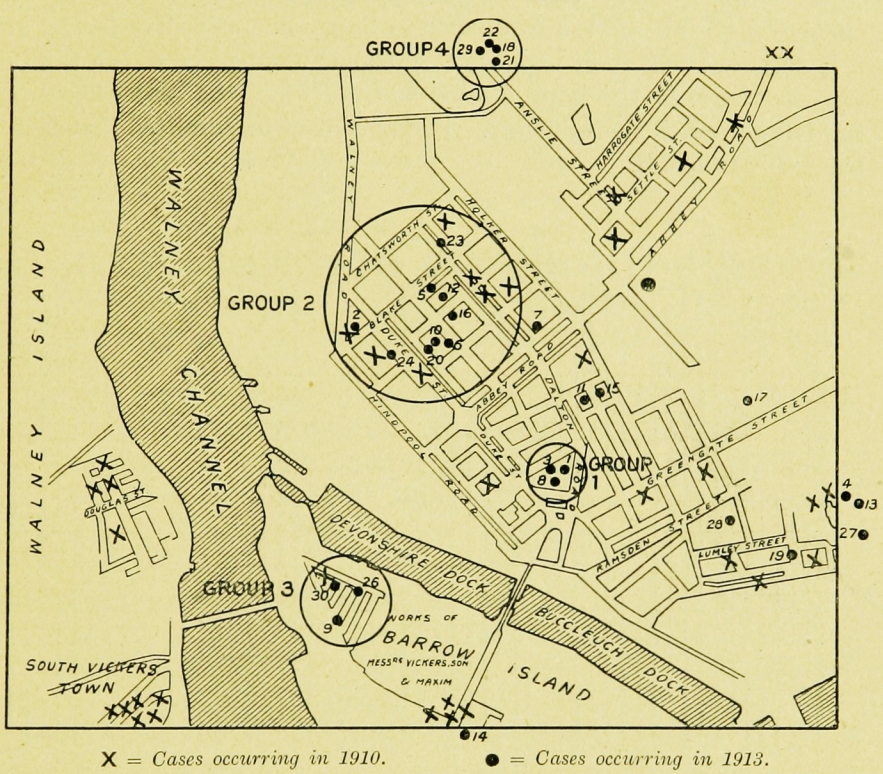


FIG. 9.—Map of Barrow-in-Furness: The x indicates the position of cases which occurred in 1910, investigated by Dr. Garrow; the ● indicate the position of cases occurring in 1913; the numbers, the sequence of the date of onset of the disease; and the circles, groups into which they are arranged by Dr. Macewen.

Garrow [10], in 1910, which left some thirty-seven cripples. So the disease when it occurred again in 1913 fell upon a locality in which the susceptibles had been picked out by the former epidemic, and the population (except for those who had come into existence since 1910) were naturally immune, or had an acquired immunity. It would seem that the susceptible material of a population is fairly soon exhausted. The disease therefore fell on those below the age of 3 years.

It is of interest also to compare Macewen's spot map of the incidence of poliomyelitis in Barrow-in-Furness, 1913, with that of Garrow's in 1910, and notice that the largest group (No. 2) tends to fall into the same area as a considerable number of Garrow's cases. This may be dependent on certain local conditions or may be due to a "virus carrier."

It seems possible that the careful investigation of the various epidemics of this disease will bring to light some causative factor, but it is essential that such investigation should take place at the time of the occurrence of the acute disease and not when the after-effects are the sole record of the epidemic. So far it must be admitted that factor has not been found.

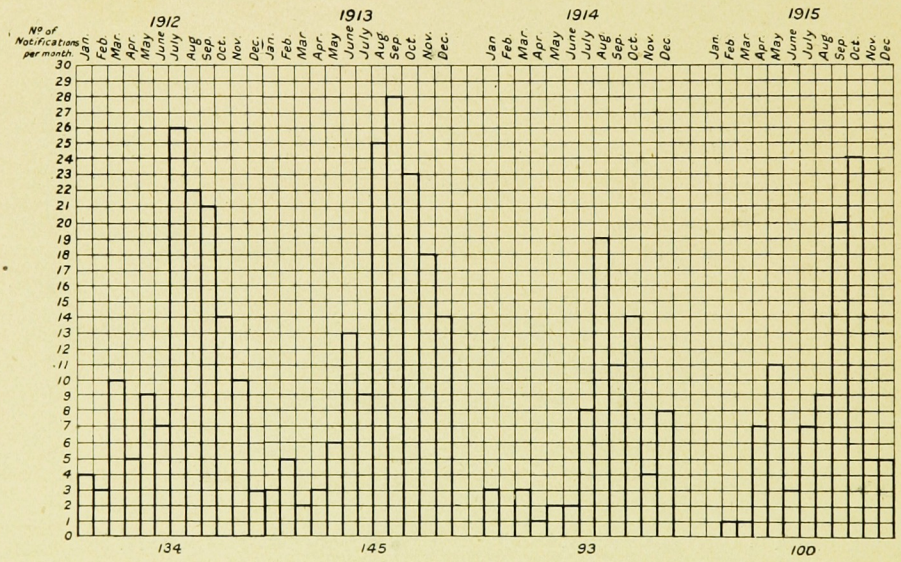


FIG. 10.—Chart showing the monthly returns of cases for years 1912-13-14-15 for the London area. It will be noted that in 1915 the maximum number of cases occurred during October, and not during August and September as in the previous years.

Jubb [15] noted outbreaks of poliomyelitis in West Kirby in three successive years—1912, 1913, 1914—one, seven, and four cases respectively. Roth [24] described a small epidemic in Oxfordshire in 1913, and Pim [22] another small epidemic in Dorset in 1914. Cases were also reported in co. Tyrone in 1914 [13].

The charts prepared from the notified cases of poliomyelitis during the past four years, both in London and the whole of England, show

that the disease has pursued the even tenor of its way with the usual seasonal incidence. There is no reason to believe that its prevalence has been greater or less than it was in years previous to notification. The chart (fig. 10) shows that the prevalence was in London somewhat greater in the year 1913 than in 1914 and 1915. In the year 1915 it is noteworthy that the maximum number of cases occurred not in August, or September, but in October.

(6) *Distribution of Cases in London.*

The study of the distribution of cases in the London area as indicated on the maps (fig. 11) would seem to point to the fact that the districts of Stepney, Islington, Hackney and Wandsworth have an exceptional incidence of the disease.

In 1913, Islington had 19 cases, Hackney 15, Wandsworth 14, and Stepney 14. In 1914, Islington had 8 cases, Wandsworth 2, and Stepney 27. In other districts there is a general evenness of distribution.

In 1914 the exceptional incidence of poliomyelitis which occurred in the East End of London (Stepney, 21 cases; Poplar, 5 cases; Bethnal Green, 5 cases—it will be noted that these figures do not accurately correspond to the notified cases, but the discrepancy is probably due to corrections of the notified returns) was investigated by Brincker [5], but he could determine no common factor. It was noteworthy that eighteen of the thirty-one cases were notified from the London Hospital. The Hospital authorities also observed that during the period when so many cases of poliomyelitis were under treatment a number of other patients were found to be suffering from herpes zoster.

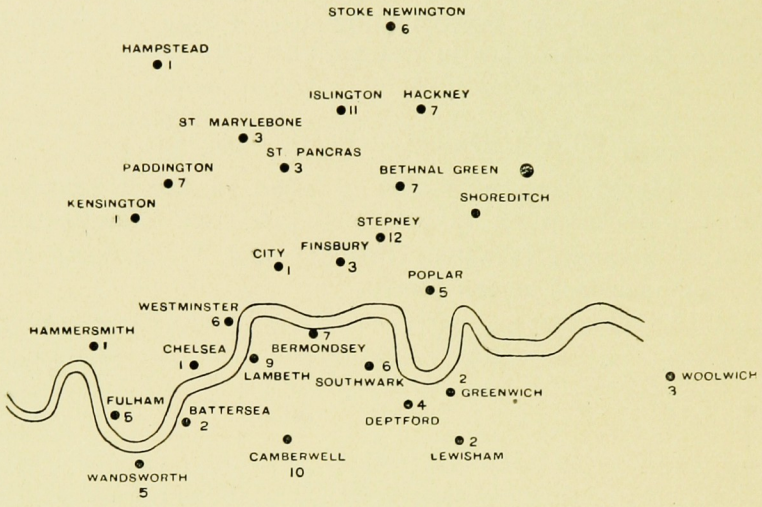
It is quite certain that the number of cases notified does not represent the full extent of the prevalence of the disease in London. It is a well-recognized fact that not a few cases of the disease, when admitted to hospital, have not been notified.

As Dr. Newsholme points out: "Although the disease is under close scrutiny by many observers in different parts of the world, there are many etiological and epidemiological problems associated with it which still require elucidation," and he invites the co-operation of the medical practitioners in attendance on the case and the local medical officer of health.

The problem is one which will need a yet larger association of workers, not only the above, but also of those versed in animal

POLIOMYELITIS LONDON 1912. JAN.1 1912 - DEC.31 1912

FROM L.C.C. RETURNS 130 CASES NOTIFIED



POLIOMYELITIS LONDON 1913 JAN.1 1913 - DEC.31 1913.

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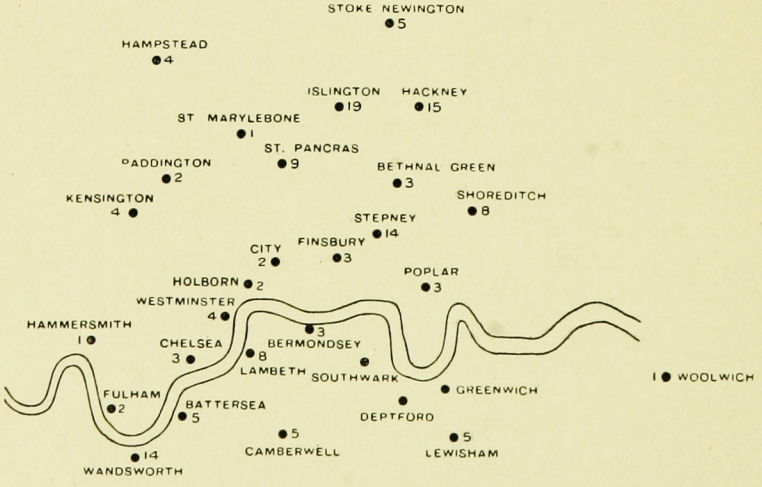
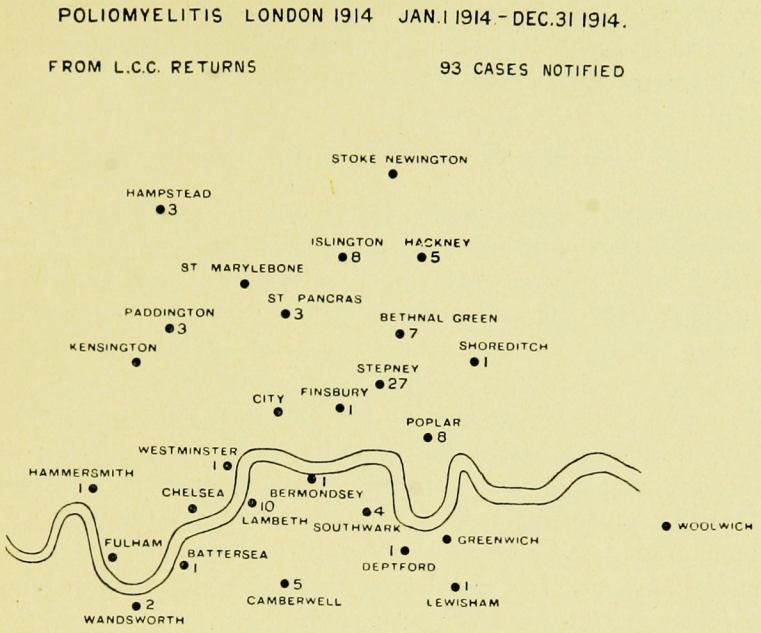




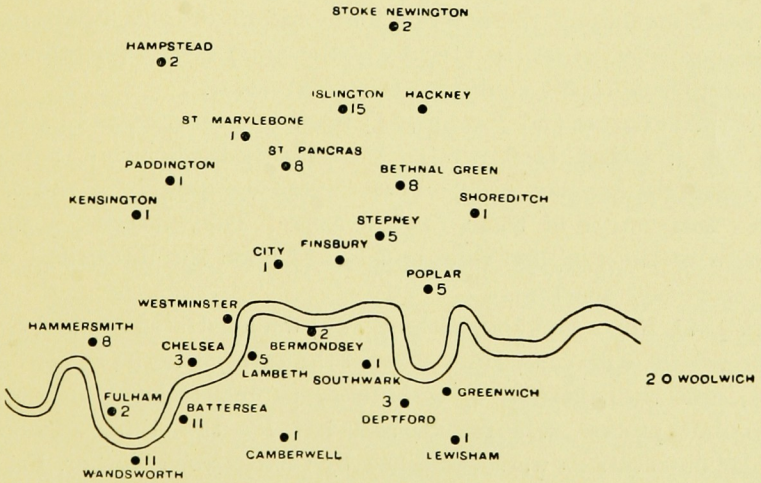


FIG. 11.—A series of maps of the London District for the years 1912-13-14-15, showing the distribution of cases in various areas.

disease, having a knowledge of the method of neurological investigation, both clinical and pathological, and skilled in bacteriological and experimental investigations.

Chapter II.—Pathological Anatomy.

Most observers of the present day regard the essential pathological change which occurs in acute poliomyelitis as an inflammation of the interstitial tissue of the central nervous system. This view has only been arrived at by the careful investigation of numerous observers in every stage of the disease. As methods of preparing and staining tissue improved, so the pathological picture has become more definite, and the views of pathologists as to the nature of the process, which at first were divergent, have become more in accord.

The leading points in the history of the advance of knowledge in this branch of the subject may be briefly stated as follows :—

Heine [38], in 1860, from clinical observation and deductive reasoning, came to the conclusion that the site of the lesion in poliomyelitis must be in the spinal cord.

In 1863 Cornil [35] investigated a case of poliomyelitis of forty-seven years' duration, and found considerable atrophy of the ventro-lateral columns and atrophy of the cells of the anterior horn. He did not, however, attach importance to the latter observation.

Then followed the observations of Prévost and Vulpian (1865) [42], who noted atrophy of the anterior horns and diminution in the number of ganglion cells, as well as atrophy of the anterior and lateral columns. Lockhart Clark (1868) confirmed this observation.

In 1870 Charcot and Joffroy [34] made an examination in a woman, aged 40, who had been paralysed for thirty-three years, and found absence of the ganglion cells, and attributed the atrophy of the muscles to the destruction of these trophic cells. They inferred a primary affection of the ganglion cells, and looked upon the interstitial change as a secondary reaction.

In 1871 Roger and Damaschino [44] demonstrated marked changes in the vessels, with cell proliferation in the anterior horns in more recent cases, and the question of a primary parenchymatous or primarily interstitial process was raised, and left for the time unanswered. Similar observations were published by Charleswood Turner, Frederick Taylor and Drummond in this country.

In 1888 Rissler [43] showed by the examination of acute cases that

the disease consisted in a disseminated infiltration and inflammatory process, which may attack any portion of the central nervous system, but showed a predilection for the grey matter of the spinal cord; but even he contends that the cells are primarily affected and the interstitial changes are secondary. He was the first to show that the pia mater might be involved.

The discussion between primary parenchymatous and primary interstitial process was carried on between numerous observers. Some pointed out the possibility of a simultaneous affection of both the parenchymatous and interstitial elements. The same process was shown to occur in both children and adults.

A series of observers now investigated acute cases, and most of them adopted the interstitial theory. In 1905 Wickman examined a number of acute cases, and in 1910 published further series. He confirmed the work of earlier observers that the process was not limited to the spinal cord, but occurred in a disseminated form in the medulla, pons, cerebrum, cerebellum, and membranes. The variation in the intensity of the process depends upon the varying richness of blood supply to the parts. The process is mainly interstitial and of the infiltrative lymphocytic type. The infiltration follows the distribution of vessels, and inflammatory œdema plays some part. Wickman considers that within the nervous system the inflammation travels along the perivascular lymphatics; the perineural lymphatics probably carry the infection from the site of inoculation to the spinal cord. Since Wickman's pathological investigation numerous workers have carried out observations on acute cases. Harbitz and Scheel consider that the infection is carried to the central nervous system by the blood as well as by the lymph-stream.

Forssner and Sjövall [37] noticed the rôle played by the phagocytes in the destruction not only of the ganglion cells but also in the spinal root ganglia, and Wickman and all recent observers confirm this observation [47].

Farquhar Buzzard, in his Goulstonian Lectures of 1907 [33], discussed the various views which had been advanced to explain the changes observed in the spinal cord. It is unnecessary to repeat these, but his conclusions in the light of recent investigation as to the nature of acute poliomyelitis, based on pathological observations, are of interest, for he says: "It is an acute specific fever occurring sporadically and epidemically; its essential lesion is an inflammation of the interstitial tissue of the central nervous system, due to the presence of micro-organisms, or their toxin, probably in the blood, but possibly in the lymph, circulating within that system."

I have already referred to the very complete observations of recent writers as to the nature of the lesion of poliomyelitis. In dealing with this part of the subject my description will be based mostly on my personal observations of human cases, not that they have been more extensive or complete than those of others, but that they are personal, and therefore more pertinent to these lectures. Endeavour has been made to include all stages and situations of the disease, and where individual observation was lacking, resource has been had to the work of others.

The changes are similar to those found in the experimental disease, *except* such as are described by Kling, Pettersson and Wernstedt [39] under the head "degeneration." Some cases of toxic neuritis show changes similar to those described by these observers, but the proof is lacking that they were cases of poliomyelitis.

Macroscopic Changes.

It may be said that the macroscopic changes observed in the body in a child dying of poliomyelitis are usually slight. Most observers have noted enlargement of the spleen, the thymus and lymphatic glands.

Flexner, Peabody and Draper [36], in 1912, had the opportunity of investigating the organs of ten children who died between the third and eleventh day of illness. Apart from the nervous system upon which the main injury is inflicted, all the cases showed hypertrophy of the lymphoid tissues. The affection of these was widespread, and included the tonsils, small intestine, thymus, and the superficial and deep lymphatic glands. The spleen was enlarged, and the Malpighian bodies prominent. The lesion in the liver consists of hyaline focal necrosis of liver cells, followed by regeneration an invasion by lymphoid cells and polynuclear leucocytes. They consider that the polymorphonuclear-cytosis of epidemic poliomyelitis is caused not only by the lesion of the nervous system, but also by lesions of the lymphatic tissue and liver. This consideration will serve to explain certain discrepancies in the cell counts in the cerebrospinal fluid removed by lumbar puncture and in the circulating blood.

The cerebrospinal fluid is clear, and no change can be noted in the pia mater or pia arachnoid. On one occasion hæmorrhage in the lumbar region was found in an acute case, but it is possible that such was due to the lumbar puncture which had been performed.

The surface of the brain appears in most cases normal, but in one case of encephalitis with hemiplegia there was obvious congestion of the

vessels on the surface. The cord may on palpation, if the disease has been extensive, feel soft, but as a rule no alteration can be noted. In long-standing cases the cord may appear somewhat shrunken, and the grey and atrophied appearance of the ventral roots, as compared with the dorsal roots, is a marked feature. On section through the cord the grey matter, especially in the region of the anterior horn, appears hyperæmic, and in some cases the whole horn may appear filled with blood. Although the hyperæmia chiefly affects the anterior horns, yet it is not limited to this portion of the grey matter. Small dark lines are seen in the white matter, indicating congested vessels, but the white matter generally appears normal.

In cases of long standing, three months or more, the grey matter has a softened and gelatinous appearance, and on section this shrinks away from the level of the section, so that there is a depression in the region of the anterior horn. In the old and long-standing cases the whole cord may be shrunken on one side, and the grey matter especially may appear obviously smaller than that of the other.

In the medulla, pons and brain, areas of congestion similar to those seen in the spinal cord may be observed, and in long-standing cases a cavity may exist in the brain, as shown by White and Worthington [46].

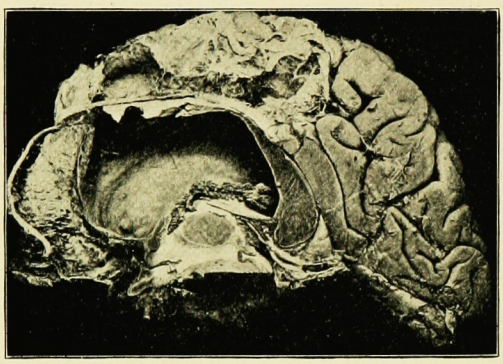
Rossi [45] describes a similar pathological condition in a case of poliomyelitis associated with an encephalitic process in the frontal, paracentral lobule and the corpus callosum. The case was that of a man who died at the age of 40. He had, when 6 months old, convulsions, followed by a paraplegia. The fits never recurred. He did not gain the power of walking. The right leg presented the typical condition of spastic paralysis with flexion of the knee and adduction of the thigh. In the left leg there was an almost complete flaccid paralysis, with wasting of muscles and shortening of the limb. Vasomotor troubles were present, and the reflexes were diminished in the left leg. The pathological examination showed in the cerebral hemisphere a condition of softening to the right and left of the mid-line with dilatation of the anterior portion of the left lateral ventricle. The cord in the lumbar region showed the typical appearance of an old poliomyelitis (figs. 12 and 13).

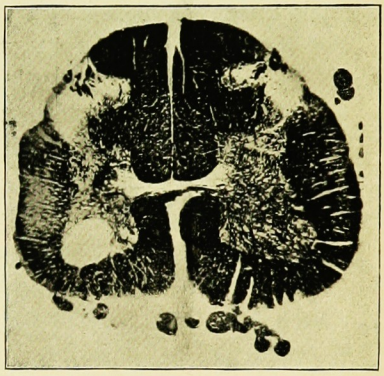
Microscopic Changes.

These will be described in three stages: (1) the acute, (2) the chronic, (3) the atrophic stage. There is, of course, no hard-and-fast

line of distinction between these stages, but specimens may be taken from cases dying within the first month as illustrative of the acute stage, two or more months after the acute onset as illustrative of the second, and two or more years after acute onset as illustrative of the third stage.

(1) *The acute stage.*—In a certain number of cases the pia mater is found to be infiltrated with small round cells: these cells are generally most numerous around the vessels in the anterior median fissure and





FIGS. 12 and 13.—Photographs of brain and spinal cord, showing a cerebral and a spinal lesion, resulting from poliomyelitis in early life.

Reproduced from the *Nouv. Icon. de la Salpêtrière*, 1907, by the kind permission of Mon. Italo Rossi and Mon. H. Meige.

may be limited to this region (fig. 15). Sometimes the infiltration extends on to the posterior surface of the cord and involves the posterior roots, but often it is limited to the anterior region of the cord.

I do not propose to enter into the discussion as to the nature and origin of these cells, either here or in the spinal cord, but shall be content to designate them lymphocytes or infiltration cells. The whole cytology of the infiltration of the vessel walls, the soft membranes and the grey matter is discussed by Buzzard [33], Wickman [47], Mackintosh and Turnbull [40], Barnes and Miller [28], and Kling, Pettersson and Wernstedt [39]. Buzzard describes five varieties of cells in the infiltration of the grey matter, and says: "Excluding all these cells, there are still a considerable number which it is difficult to classify, and for this reason it is impossible to gauge accurately the relative proportion of the various elements. My general impression is that neuroglial proliferation and lymphocytic infiltration are the most

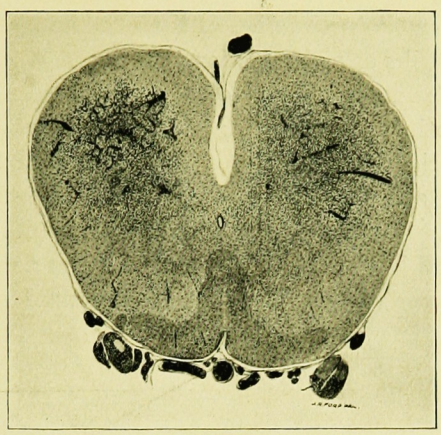


FIG. 14.—Lumbar region of cord of a child who died on the twenty-eighth day after onset of illness, showing extreme vascular congestion and infiltration of the grey matter most marked in the region of the anterior horns.

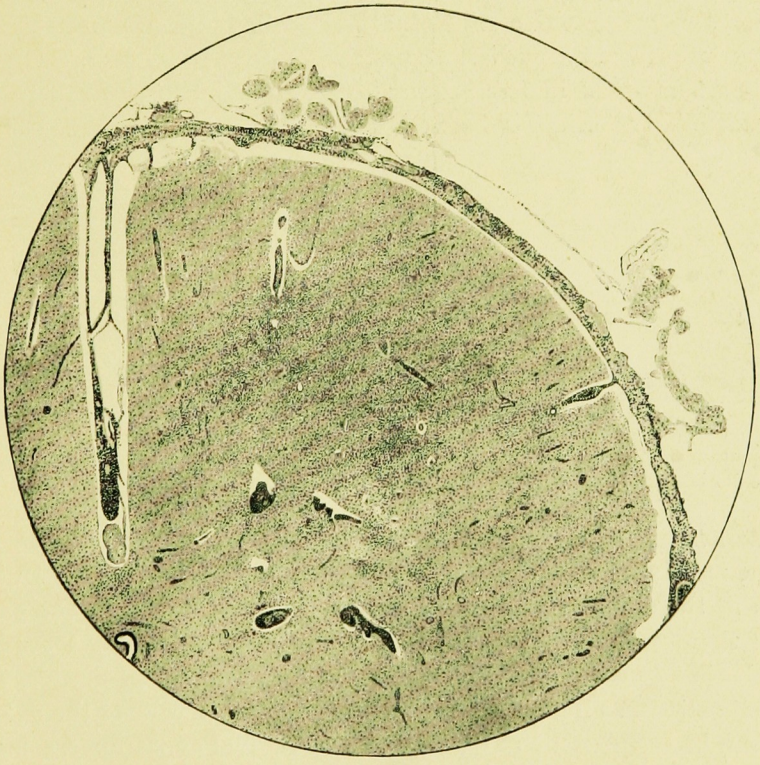


FIG. 15.—Section of spinal cord of a child who died on the ninth day of illness, showing infiltration of the grey matter, perivascular infiltration and invasion of the pia arachnoid membrane. Note that the cells of the anterior horn can still be seen in the infiltrated area.

prominent factors in the production of these cell masses." Mackintosh and Turnbull describe seven varieties of cells.

Spinal cord: The appearance of the spinal cord when stained by the Van Gieson method is very striking (fig. 14): the vessels, and especially those in the anterior median fissure, are dilated and surrounded with small round cells, and the grey matter in the regions of the anterior horns is infiltrated with these cells (fig. 15). The white matter shares to a limited extent in this infiltration, as do also the vessels passing from the pia into the cord, which is in the case figured markedly involved on the anterior surface (fig. 16).

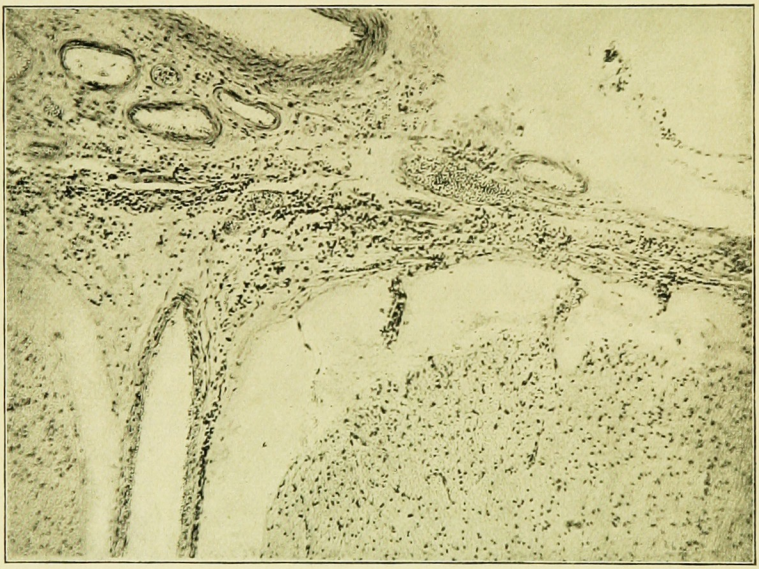


FIG. 16.—Photograph of the same section of spinal cord under high magnification to show small-celled infiltration of the layers of the pia lying next to the spinal cord and the perivascular infiltration of the vessels passing into the cord.

Extravasations of blood, large and small, can be seen in the grey matter, mostly in relation to vessels, both veins and arteries. In later stages of the disease the vessels may appear thrombosed; in the earlier stages there is no evidence of this, though at one time I regarded thrombosis as a cause of the softening [31]. In the grey matter, when the infiltration has not been too extensive, the large cells of the anterior horn can be seen—some of them present a normal appearance, some are surrounded by infiltration cells, and others, again, are being destroyed by phagocytic neuroglia cells (neuronophagia) (fig. 17). Some of the

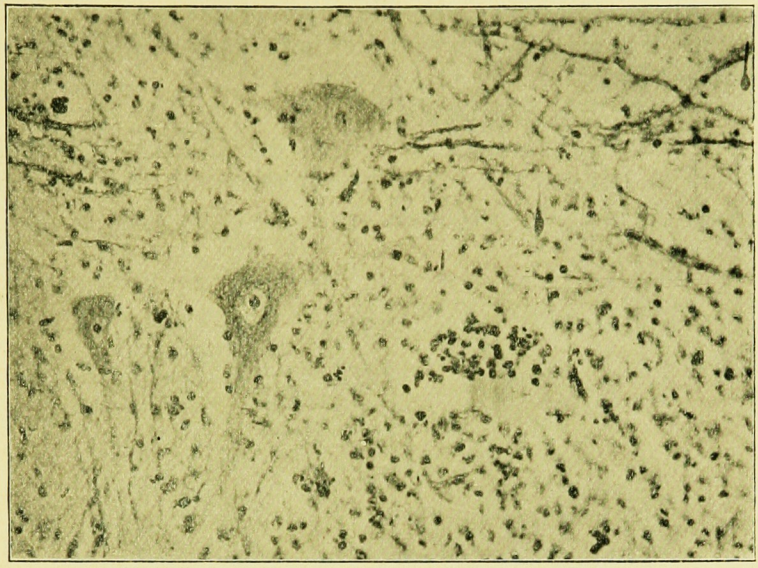


FIG. 17.—Photograph of the ganglion cells of the anterior horn of the same case, showing varying degree of "neuronophagia." Note (i) the cell with a distinct nucleus and nucleolus, with "neuronophagic" cells adherent to the wall, (ii) the cell with indistinct nucleus and "neuronophagic" cells within its substance, and (iii) a cell wholly replaced by "neuronophagic" cells.

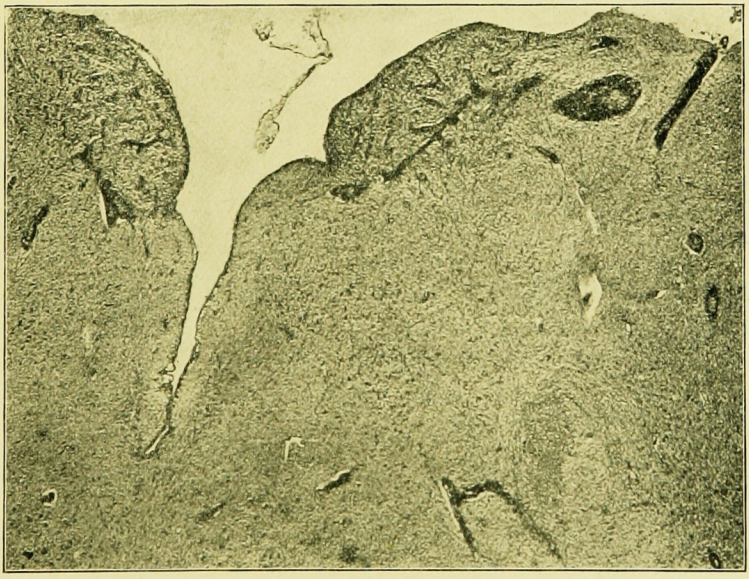


FIG. 18.—Section of medulla and fourth ventricle taken from a child who died forty-eight hours after onset of disease, showing extreme congestion and perivascular infiltrations of vessels and lining membranes of the fourth ventricle; there was also extensive poliomyelitis of the spinal cord.

ganglion cells are entirely replaced by neurophagic cells. Portions of the grey matter other than the anterior horns may be affected, and the changes are similar.

The posterior root ganglia show the same cellular infiltration and cytological changes. Flexner states that experimentally lesions of the ganglia are as common and constant as the lesion of the grey matter, and in man are probably as constant, but not so frequently looked for.

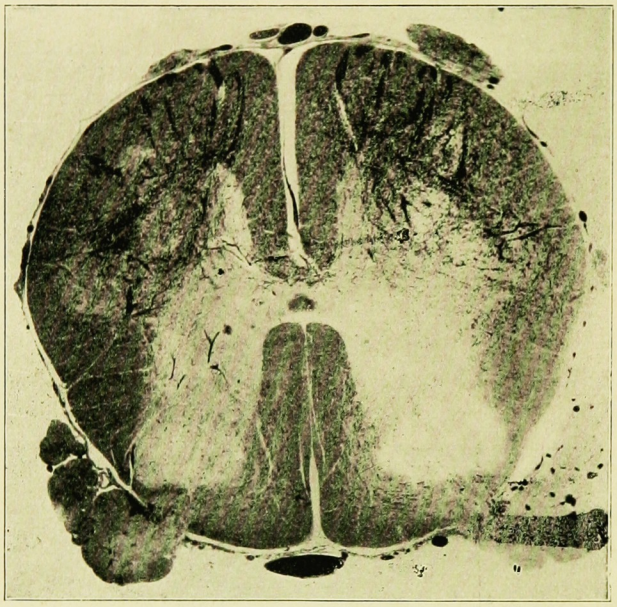


FIG. 19.—Section of spinal cord of a child who died six weeks after the onset of the disease, stained by Marchi method, showing degeneration of the efferent fibres of the anterior roots.

In the medulla and mid-brain changes similar to those in the spinal cord can be observed, and these are present in cases which, during life, have exhibited no marked bulbar or pontine symptoms. In the specimen shown (fig. 18) the poliomyelitic changes are most marked in the region of the fourth ventricle and invade the lining membranes of that cavity. The boy from whom this specimen was taken rapidly passed into coma and died in forty-eight hours.

One interesting case of facial paralysis on one side is on record in which the seventh nerve nucleus on that side was destroyed, while that on the opposite side was unaffected [30].

(2) *Chronic stage.*—The study of the changes in the spinal cord

during the chronic stages is of considerable interest. They show the local destructive lesion giving rise to necrosis, to secondary degeneration taking place in the efferent portions of the anterior root, and to degeneration of antero-lateral tracts in the spinal cord resulting from these lesions (fig. 19). In general, the lesion is too diffuse to be of much service for tracing the endogenous fibres of the cord, but Mott [41] has

FIGS. 20, 21, 22.—A series of three sections taken from the lumbar cord of a child who died seven weeks after the onset of the disease: (i) stained by Marchi method; (ii) by Weigert Pal method; and (iii) by Van Gieson method.

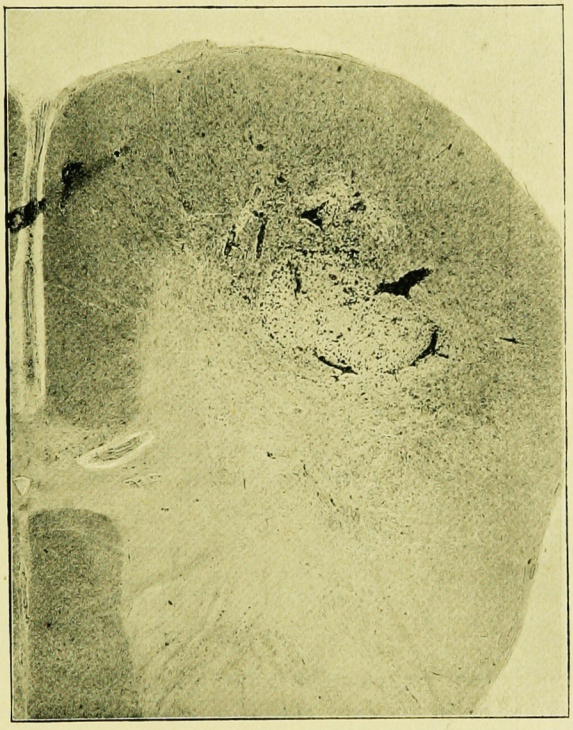


FIG. 20.—Gives a positive picture, the degenerated myelin and the fat in the cells in the perivascular space being stained black.

been able to trace such in one case, and Holmes and myself [32] were able to trace the intra-medullary course of the spinal portion of the spinal accessory nerves in another.

During this stage the changes are best shown by the Marchi and Weigert-Pal method. The Marchi stains the degenerate myelin tissue black, whilst the Weigert-Pal stains the normal fibres a dark blue. Positive and negative pictures are therefore presented respectively.

Fig. 20 represents a section through the lumbar region of the cord and shows an area of necrosis, limited to the external portion of the anterior horn. The vessels are stained black, owing to the loading of the perivascular lymphatics with the products of degenerated myelin. In the antero-lateral tract of the spinal cord numerous black dots can be seen, representing degenerated fibres.

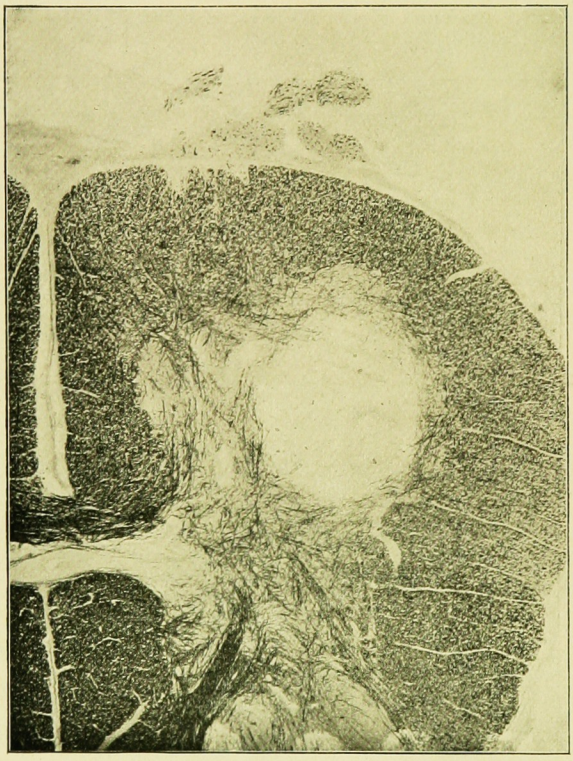


Fig. 21.—Gives a negative picture, the area of complete degeneration being white—the number of the medullated fibres in the grey matter of the anterior horn is diminished.

If this positive picture is compared with the negative picture presented by the Weigert-Pal method (fig. 21), it is clear that the destruction of tissue is widespread, and in some directions more extensive than that presented by the positive picture. The myelin sheaths have been destroyed for a considerable distance beyond the necrotic area, so that practically the whole of the anterior horn is involved, though not to the complete extent to which the external portion has suffered. The products of degeneration have to a considerable extent been removed from the peripheral portions of the lesion.

The specimen stained by hæmatoxylin (fig. 22) shows the remains of the inflammatory process and the formation of new tissue.

(3) *Atrophic stage* (two years or more).—In the *atrophic stage* the products of necrosis become absorbed—the anterior horns undergo shrinking, and the whole of the grey matter on the affected side becomes atrophied. The white matter also suffers, but relatively less than the

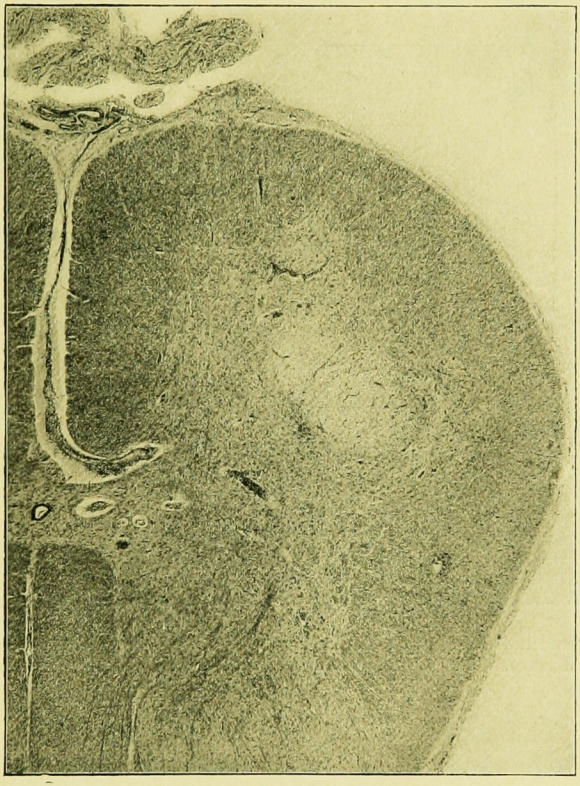


Fig. 22.—Gives a positive picture, the glia tissue with but few cellular elements taking the place of the degenerated tissue.

grey matter, and the whole of the anterior lateral tracts of the cord are pale and diminished in size, and in some cases a sclerotic area is left in the anterior horn (fig. 13).

Peripheral nerves: In the acute stage, cell infiltration can be found in the peripheral nerves (fig. 23), but it is difficult to say that such infiltration produces any symptom or pathological effect. The observations on the point are not extensive, and need further investigation. The

specimen (fig. 23) is taken from the anterior crural nerves of a boy, aged 5, who died on the ninth day after the onset of acute poliomyelitis. In long-standing cases the Marchi method shows the usual degeneration of the efferent fibres. The Weigert-Pal method shows that the number of normal fibres left in a degenerated nerve is very considerable: such fibres are usually of large size, and are probably largely afferent in function. No true interstitial change can be found in the nerves.

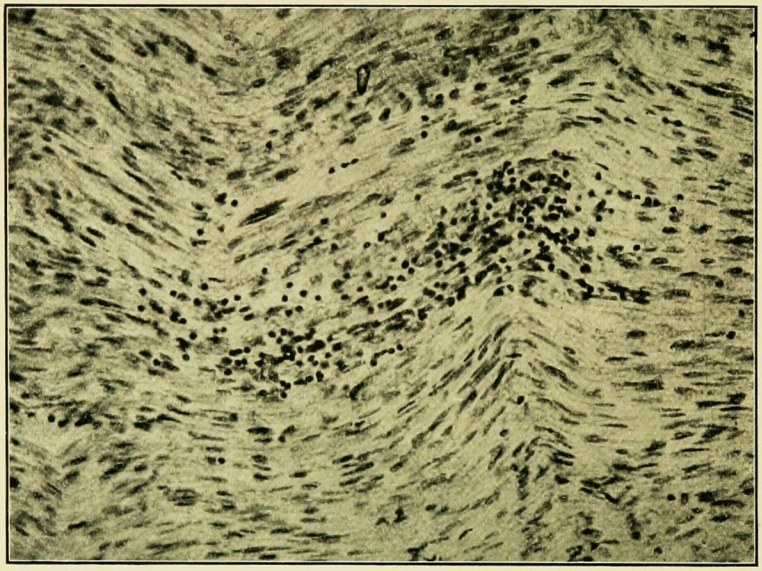


FIG. 23.—Longitudinal section of anterior crural nerve of a boy who died on the ninth day of the disease. The specimen shows round-celled infiltration of the nerve.

Muscles. The study of the muscle in the chronic and late stages of the disease is of interest. A muscle which is not wholly degenerated shows normal muscle-fibre alongside with fibres and bundles of fibres which have undergone complete degeneration and been replaced by fibrous tissue. In those cases in which the muscles have undergone complete fibrous or fatty degeneration, it is interesting to note that the muscle-spindles still exist [29], and contain a normal and well-striated muscle-fibre and a normal nerve. It is a striking fact that certain muscles seem to undergo a fibrous degeneration, whilst others undergo a fatty degeneration. As an instance of this former may be mentioned the biceps, as an instance of the latter the gastrocnemius.

In concluding this review of the pathology of the subject, it may be

said that so far as our present knowledge goes the pathological picture above presented is (with the exception of rabies) distinctive of the virus of poliomyelitis.

Chapter III.—Experimental Poliomyelitis.

(1) *Earlier Experimental Work.*

In 1909 Landsteiner and Popper succeeded in transmitting poliomyelitis to two monkeys, but failed to propagate the experimental disease beyond the first generation. In the same year Knöpfelmacher and Strauss and Huntoon in America were also successful in producing the disease in monkeys by injecting into the peritoneum an emulsion of the spinal cord from cases of poliomyelitis.

Flexner and Lewis, in 1910, overcame the difficulty of propagation by substituting intra-cerebral for intra-peritoneal injection, and were the first observers to transmit the disease through a series of monkeys. As Flexner points out, the choice of an intra-cerebral route as superior to the intra-peritoneal route was not haphazard, as all the severe effects of poliomyelitis are inflicted on the nervous system, and, upon reflection, this fact at once suggested that the parasitic cause of the disease must find favourable conditions for multiplication within the nervous tissues [49].

Landsteiner and Levaditi showed that the virus would pass through porcelain filters and also that glycerine did not destroy it. Working on the same lines and at the same time, Leiner and Wiesner in Vienna, Roemer and Joseph in Marburg, Krause and Meinicke, confirmed these observations and added much to the knowledge of the nature of the virus [48], [50].

(2) *Properties of the Virus.*

(*a*) *Filterability.* — It was shown by Flexner and Lewis and Landsteiner and Levaditi that the virus would pass through a porcelain filter. The latter observers noted that it would pass through the Berkefeld, Chamberland, Reichel and Pukall filters, but that, after such a passage, the virus lost some of its virulence, and the incubation period was always prolonged, and the monkey either did not die or only died some days after the development of the disease.

(*b*) *Glycerine resistance.*—It has been shown by Landsteiner and Levaditi that the virus will resist the action of glycerine either concentrated or with 50 per cent. of water without impairing its

virulence. The virus has been kept by Flexner for twenty-five months in glycerine at a temperature of 4° C. without affecting its virulence. In this respect it resembles that of rabies and vaccinia.

(*c*) *Resistance to drying.*—Flexner and Lewis, Landsteiner and Levaditi, found that prolonged drying, even for twenty-four days, at a temperature of 22° C. did not diminish the virulence, so that in this respect it differed from rabies. Leiner and Wiesner, however, found that drying of thin films for four hours at a temperature of 37° C. did destroy the virulence. They showed that the virus is killed by exposure to a temperature of 55° C. for half an hour, and it is not killed by exposure to a temperature of −8° C. Flexner found that long exposure (eighteen to thirty-six months) to a temperature of −2° C. to −4° C. did destroy the virulence of the virus.

(*d*) *Resistance to disinfectants.*—It has been shown by Landsteiner and Levaditi that 0·2 per cent. solution of potassium permanganate will kill the virus in one hour at a temperature of 39° C., and that 6 per cent. peroxide at the same temperature will destroy the virus in forty-five minutes. The virus is not killed by ½ to 1½ per cent. of carbolic acid.

(3) *Cultivation of the Organism.*

In October, 1913, Flexner and Noguchi [59] published the method by which they had succeeded in cultivating the organism of poliomyelitis under anaerobic conditions in ascitic fluid to which fresh rabbit's kidney has been added.

The micro-organism consists of globoid bodies measuring from 0·15 μ to 0·3 μ in diameter, and arranged in pairs, chains and masses, according to the condition of growth and multiplication. The chain formation takes place in a fluid medium, the other grouping in both solid and fluid media. Within the tissues of infected human being and animal, the chains do not appear. Whether the micro-organism actually belongs to the bacteria or to the protozoa has not been determined, but it is pointed out that the organism is associated with the production of an acute disease in which suppuration does not form a prominent part.

The experimental disease caused by the inoculation of cultures resembles that produced by the virus of poliomyelitis as ordinarily employed. The cultivated micro-organism withstands the action of glycerine, passes through the Berkefeld filter, and the filtrates yield, upon recultivation, the particular organism contained within the filtered culture. By employing suitable staining methods the micro-organism

can be detected in film preparations and in sections of nervous tissue from monkeys infected with cultures. The organism thus fulfils the condition hitherto demanded for the establishment of causal relations between an extraneous parasite and a specific disease: The micro-organism exists in the infectious and diseased organs; it is not, so far as is known, a common saprophyte or associated with any other pathological condition; it is capable of reproducing on inoculation the experimental disease in monkeys, from which animals it can be recovered in pure culture. Besides these classical requirements, the micro-organism withstands preservation and glycerination, as does the ordinary virus of poliomyelitis within the nervous organs.

Flexner and Noguchi, in conjunction with Amoss [51], [60], have now continued their investigation of the organism further, and having carried the strain through twenty subcultures have proved that the final culture was pathogenic to monkeys.

The micro-organism isolated from poliomyelitic tissues may possess pathogenic properties after having been cultivated artificially for a period of a year or more, and after an almost indefinite degree of dilution of original nervous tissues from which it was derived.

The micro-organism cultivated from poliomyelitic tissue is adapted with difficulty to saprophytic conditions of multiplication, but once adapted growth readily takes place upon suitable media. When, however, as a result of inoculation into monkeys the parasitic propensities of the micro-organism are restored, it again displays the same marked fastidiousness to artificial conditions of multiplication present at the the original isolation.

Flexner, Noguchi, and Amoss end their paper with the following guarded conclusions:—

That the experiments afford additional strong evidence in support of the view already expressed that the micro-organism bears an etiological relationship to epidemic poliomyelitis in the human subject, and to experimental poliomyelitis in the monkey.

(4) *Method of Infection.*

The emulsion is prepared by pounding up 1 grm. of the infected portion of the spinal cord with 20 c.c. of normal saline solution; 0·5 c.c. of this emulsion is injected into the brain and 4 c.c. to 5 c.c. into the peritoneal cavity (Roemer). The amount of virus required is extremely small—viz., less than $\frac{1}{1000}$ c.c. of a 2·5 suspension of spinal cord.

The most certain method of producing infection is by injection of

the virus into the brain. Injection into the peritoneal cavity, the anterior chamber of the eye, the subcutaneous tissue, intraspinal, intraneural, and intravenous injections have all been successful in producing the disease.

It has been shown (Flexner and Lewis, Levaditi and Landsteiner) that the virus injected into a peripheral nerve gives rise to paralysis, the disease commencing in the limb corresponding to the nerve injected.

Leiner and Wiesner found that if the nerve is divided immediately after the introduction of the virus into the peripheral end, the spread of the disease is prevented. In whatever way the animal is infected it is in the central nervous system, and especially the grey matter of the cord, that the virus tends to locate itself.

Leiner and Wiesner showed that the virus could pass through the gastro-intestinal mucosa, but other observers, Levaditi and Landsteiner, failed to obtain positive results, and suggest that infection only takes place if there is a previous lesion of the intestinal walls. Leiner and Wiesner, in order to avoid the action of gastric juice, injected the virus into certain portions of the intestines after opening the abdomen. Three of the four monkeys thus operated on developed poliomyelitis. Flexner, Clarke and Dochez showed [57] that the virus could survive the action of both the gastric and intestinal secretions.

The virus will pass the nasal mucous membrane if injured (Landsteiner and Levaditi), but Leiner and Wiesner have shown that it will pass the uninjured mucous membrane. Natural contagion has been reported in a monkey which was kept in a cage in which the virus had been smeared over the bars; non-infected monkeys have been kept in close contact in the same cage with infected monkeys without contracting the disease (Levaditi and Danulesco [65]).

The great epidemic of poliomyelitis in Sweden, in 1911, gave the observers Kling, Pettersson, and Wernstedt [64] the opportunity of an investigation on somewhat different lines from those previously adopted. They obtained washings from the mouth, nose, pharynx, upper air-passages, and small intestine of a number of patients—(1) dead of the disease; (2) living cases; (3) abortive cases; (4) healthy persons in contact with infected individuals. Washings from these mucous membranes were filtered through a Heims asbestos filter, and by a combined intraperitoneal injection with an inoculation into one sciatic nerve of the filtrate they succeeded in infecting monkeys.

(1) *Dead of the disease.*—Out of fourteen patients dead of poliomyelitis thus investigated, in only one were the authors unsuccessful in demonstrating the presence of the virus of poliomyelitis.

It is, however, interesting to note that the changes in the spinal cord, which have been considered most characteristic of poliomyelitis —i.e., cellular infiltrations—were not always present. In fact, out of fifty-nine monkeys which were infected from typical cases of poliomyelitis, twenty-five—i.e., 42 per cent.—showed infiltrative changes, and thirty-four—i.e., 58 per cent.—degenerative changes.

(2) *Living cases of poliomyelitis.*—Having obtained results from persons dead of poliomyelitis, the authors next proceeded to investigate the secretions from living persons, and they obtained material from the mouth, nose, pharynx, and large intestine of twelve living persons suffering from poliomyelitis. In only one case did the observers fail to infect the monkeys.

Thus the presence of the microbe has been detected in the secretions of one of the examined membranes—i.e., mouth, nose, upper air-passage, or intestine—in twenty-four out of twenty-six cases.

Considering the difficulty of infecting monkeys in every instance, the observers consider themselves fully justified in drawing the following conclusion, viz., that the virus in all probability is always present in the mucous membranes of the nose, mouth, pharynx, and the intestine of persons affected by poliomyelitis during the acute stage of the disease.

(3) *Abortive cases, and* (4) *healthy persons in contact with infected individuals.* — Having obtained results from persons suffering with definite poliomyelitis, the authors proceeded to investigate the washings from the mucous membranes of abortive cases and healthy persons. In a family of five, one of whom had definite poliomyelitis, two an uncertain illness of short duration, and two had remained well, they showed that three carried the microbe of poliomyelitis in their mucous membranes—viz., the one who had distinct paresis, one of those who had had an abortive attack and one of those who had had no illness.

The existence of the micro-organism of poliomyelitis has been demonstrated also in the secretion from the mouths of three persons who had not, as far as is known, had any contact with patients showing definite paresis, persons whose illness was characterized by such vague symptoms that only in one case did the suspicion arise that some form of poliomyelitis was present.

In six families the experimental method has demonstrated the existence of carriers of the virus in several members of the family, only one person in each family having typical paralysis. It is therefore probable that virus carriers are very common.

Flexner, Clark and Frazer [58], dealing with passive human

carriage of the virus, demonstrated its presence in the throats of the parents of a child suffering with the disease and confirm in this respect the above observations.

Intraspinous infection.—So far no one has detected the virus in the cerebrospinal fluid in human cases of poliomyelitis, and it is usually absent in the spinal fluid of monkeys at the time of the onset of paralysis, although it may be present at an earlier period after intracerebral inoculation.

Flexner, and Clark and Amoss [52] [54], carried out a series of experiments of infecting monkeys by the method of intraspinous injection of the virus. They experienced no great difficulty in securing infection by this route, although somewhat larger doses of an active virus were required. The virus could be demonstrated in the sub-arachnoid spaces for forty-eight hours after injection, but it was no longer present on the sixth day, at the time when the first symptoms of infection had made their appearance. The failure of the cerebrospinal fluid from human and experimental cases of poliomyelitis to produce the disease when inoculated into monkeys is due to the fact that the virus is either fixed by the nervous tissue or has passed into the blood, which tends to destroy it.

Propagation of the virus by the blood-stream.—It is recognized that the intravenous method of inoculation, even when such large quantities as 50 c.c. to 100 c.c. of the virus are used, is an uncertain and inconstant method of producing infection, although so small an amount as 0·5 c.c. of the same virus succeeds when introduced into the brain. It has also been shown that when infection does occur the incubation period is greatly delayed, in one instance to nineteen days, and during this period the cerebrospinal fluid contained the organism [53].

Flexner and Amoss [54] have made a careful study of this point, and by a series of experiments they trace this discrepancy to the apparent inability of the virus to enter directly the substance of the brain and spinal cord from the blood.

In order to reach these organs the virus must leave the blood and pass into the cerebrospinal fluid, and this it can only do if the choroid plexuses are rendered unduly penetrable, either by excessive doses of the virus or by aseptic inflammation produced by the injection of horse serum.

In the passage of the virus through the cerebrospinal fluid they have shown that it is possible to prevent infection by the injection of an immune serum in the sub-arachnoid space by lumbar puncture. The

virus when injected into the blood is deposited promptly in the spleen and bone-marrow, but not in the kidney, spinal cord, or brain, but the inter-vertebral ganglia remove the virus from the blood earlier than does the spinal cord or brain. They believe that these experiments support the view that the infection in epidemic poliomyelitis in man is local and neural and by way of the lymphatics, and not general by way of the blood; hence they uphold the belief that the entrance is from the upper respiratory mucous membrane.

Incubation period.—The incubation period is subject to very considerable variations. The variations depend upon—(1) The method of injection; (2) the amount of virus given; and (3) the method of treating the virus before injection. Of eighty-one monkeys infected by Lewis and Flexner, forty-seven became paralysed between the eighth and the twelfth day, eighteen became paralysed before the eighth day, and sixteen after the twelfth day. Levaditi found the average incubation period from seven to ten days, and Roemer gives the incubation period as nine days.

In Kling, Pettersson and Wernstedt's series, although the incubation varies within very wide limits, yet the average duration works out at nine to ten days.

The following factors were found to govern the incubation period: The less virulent the material, the longer was the incubation period. Filtration diminished the virulence (Levaditi and Landsteiner, Leiner and Wiesner). Thus an unfiltered emulsion produced poliomyelitis in seven days; the same quantity of filtered emulsion produced poliomyelitis in twenty-seven days.

The quantity given also alters the incubation period. Dilution, again, has the same effect, and if diluted beyond a certain limit the virus will not produce poliomyelitis (Roemer). Thus an animal, injected intra-cerebrally with 0·5 c.c. of a 5 per cent. spinal cord emulsion, became paralysed on the seventh day and died on the eighth day. Another monkey, inoculated with the same quantity but ten times less concentrated, became ill on the twelfth and died on the thirteenth day. Another monkey, injected with the same quantity 100 times diluted, survived without having manifested any paralytic symptoms.

Leiner and Wiesner found that inoculation of a very concentrated virulent emulsion appeared to exercise rather an unfavourable influence on the development of poliomyelitis. The incubation period was slightly longer and the course of the disease goes on as if in the nervous tissues there were, in addition to the acting virus, certain preventive substances which exercised a neutralizing action on the virus.

What happens during the incubation period? Leiner and Wiesner showed that the virus spread to the nervous system before it was possible to observe any morbid manifestation in the central nervous system. Levaditi and Landsteiner found that the anatomical and pathological alterations commenced at a time very close to the outbreak of clinical signs. The virus of poliomyelitis can invade the nervous system and multiply there without causing for a time any apparent trouble or distinct lesion. The paralytic phenomena in a monkey may commence very suddenly—i.e., the monkey may be quite well in the morning and completely paralysed by the evening. It is a striking fact that in the majority of cases, in spite of the inoculation of the virus into the brain, the disease commences by paralysis localized to the lower extremities.

(5) *Immunity.*

On clinical grounds there is good reason to believe that an individual who has survived an attack of poliomyelitis is immune to a second attack. Experimentally it has been shown by Flexner and Lewis, Levaditi and Landsteiner, and Roemer that monkeys which have survived the acute period of infection are immune to a fresh dose of the virus. Roemer considers that immunity is only acquired after about the twenty-fourth day, but other observers do not confirm this observation.

In one case Leiner and Wiesner have been able to reinfect a monkey which was paralysed for eighteen days. This is probably an exceptional instance. Leiner and Wiesner performed experiments to determine if the nervous system of monkeys, killed after the acute state had passed and the refractory stage reached, contained an appreciable quantity of active virus. They found that they could transmit the disease by using the spinal cord of a monkey killed on the twenty-fourth day of the disease. This would seem to show that the active virus and the antibodies can exist at the same time and in the same individual.

Production of artificial immunity.—Levaditi and Landsteiner used the same method for rendering a monkey immune against poliomyelitis as is used for producing immunity against rabies. To a certain extent this method was successful, but in some cases poliomyelitis has been produced by injection of the dried cords. Flexner and Lewis, by giving injections of diluted virus, were able to make monkeys immune to many times the lethal dose.

After recovery from poliomyelitis, both natural and experimental, it has been shown that an active immunity has developed. The state

of immunity is associated with the occurrence in the blood of principles that neutralize the virus. Netter and Levaditi showed this in human cases [68].

Flexner, Clark and Amoss [56] carried out a series of experiments to determine whether antibodies existed within the cerebrospinal fluid. It is known that antibodies are not secreted in appreciable quantities in the cerebrospinal fluid. The experiments show that the cerebrospinal fluid of convalescents tends to be devoid of the neutralizing immunity principles for the virus of poliomyelitis, although they may exceptionally be present within the fluid.

(6) *Experimental Investigations with the Object of Determining the Possibility of Transmission of Poliomyelitis by Means of Dead Objects and Flies.*

Flexner and Lewis, Landsteiner and Levaditi and Roemer found that prolonged drying, even for twenty-four days at a temperature of 22° C., did not diminish the virulence of the virus. Leiner and Wiesner, however, found that drying of the film for four hours at a temperature of 37° C. did destroy the virus. Landsteiner, Levaditi, and Pastia found that the virus remained potent in sterile milk and sterile water for at least thirty-one days.

Josefson succeeded in producing experimental poliomyelitis with a handkerchief and fancy work which had been in contact with a patient suffering from poliomyelitis. Neustaedter and Thro succeeded, after many failures, in producing poliomyelitis in a monkey with a filtrate of macerated dust collected from rooms in which cases of poliomyelitis had been nursed.

Howard and Clark [62] showed that the domestic fly can carry the virus of poliomyelitis in an active state for several days upon the surface of the body, and for several hours within the gastro-intestinal tract, and that the bed-bug has taken the virus with the blood from infected monkeys and maintained it in a living state within the body for a period of seven days.

Lice have not taken the virus out of the blood of monkeys or maintained it in a living state. Kling, Pettersson, and Wernstedt failed to communicate the disease by the means of fleas.

Rosenau, in 1912, demonstrated that poliomyelitis could be transmitted from monkey to monkey by the means of the bite of the stable-fly (*Stomoxys calcitrans*), and this observation has been confirmed by Anderson and Frost. These experiments are the more remarkable,

for it is a matter of some difficulty to infect a monkey with the blood of a patient suffering from poliomyelitis, and as a rule a considerable quantity is required.

Clark, Fraser and Amoss [53], in 1914, conducted a further series of experiments with Stomoxys which gave wholly negative results, and a second series conducted by Anderson and Frost were similarly negative, as were also those of Sawyers and Herms.

Francis [61] made an attempt to transmit poliomyelitis by the bite of *Lyperosia irritans* (a blood-sucking fly), but the experiments yielded entirely negative results.

The whole of the experimental evidence is strongly against the communication of the disease to man by the means of fleas, lice, bugs, and flies.

(7) *Variation in the Pathogenicity of the Virus.*

Flexner and Clark state that they have succeeded in implanting upon monkeys all ten strains of human virus which they examined. That is to say, monkeys have been infected from ten human cases. These authors state that other experimenters have only been able to implant about one-half of the human strains of poliomyelitic virus upon monkeys. In order to succeed in all instances, it is necessary to inoculate emulsions of the human spinal cord, and preferably to make double inoculation into the brain and peritoneal cavity.

English strains have only twice been implanted on monkeys: (1) Levaditi [66] in Paris, with material supplied to him by Gordon from the Cornish epidemic in 1911, succeeded in reproducing the disease from the spinal cords of three cases out of four sent to him; (2) McIntosh and Turnbull [67] in 1913 succeeded in two out of four cases from the London Hospital.

The human strains of the virus not only infect monkeys less readily than do the modified or monkey strains, but the experimental disease produced by them is less severe and less fatal. After the strains have once become wholly adapted to the monkey the paralytic disease appears in a more severe form and the degree of infectivity rises, so that exceedingly minute doses of a filtrate are capable of producing constant infection.

Flexner says the Swedish virus of 1911 appears to be the most powerful yet studied; this is indicated by the fact that saline washing of the nose, throat and intestine could be inoculated successfully after removal of all bacteria by filtration, in nearly every instance.

In America it has been difficult to procure infection with these materials, from which it has been concluded that the virus displays degrees of infectiveness to monkeys. This is further borne out by the difficulty of transmitting the sporadic English cases, as shown by McIntosh and Turnbull.

Natural Variation in the Pathogenicity of the Virus.

Flexner, Clark and Amoss [56] found that a strain of poliomyelitic virus propagated in monkeys for four years displayed during that time three distinct phases of virulence. At the outset the virulence was low, but by animal passage it quickly rose to a maximum; the maximum was maintained for about three years, when without known changes in the external conditions a diminution set in and increased until at the expiration of a few months the degree of virulence about equalled that present at the beginning of the passage in monkeys.

By resorting to the original specimen from which the virus was obtained a highly virulent strain was again produced. It is clear, then, that the frequent and long-continued passage through monkeys finally brings about a depression of virulence, whilst preservation in a state of latency for a period equally great exerts no depressing action.

The cycle of changes in virulence is correlated with the wave-like fluctuations in epidemics of diseases, which also consist of a rise, temporary maximum, and fall in the number of cases produced.

It is this variation in the epidemic which has led to the formulation of the hypothesis of concomitant causes of von Pettenkofer and of Nägeli.

Whilst the one supposes a necessary ripening of the microbic agent in the earth as a pre-requisite, the other invokes the co-operation of a second, although unknown but subsidiary, micro-organism. In these experiments of Flexner, Clark and Amoss we have an explanation of the wave of epidemic disease due to variation in the quality of the virulence of the micro-organism causing the disease.

(8) *The Clinical Picture of Experimental Poliomyelitis in Monkeys.*

The clinical picture of experimental poliomyelitis in monkeys as described by Landsteiner and Levaditi, Flexner and Lewis, and others is similar to that which occurs in man. In addition to the ordinary type of limb paralysis, the muscles of the face, the oculo-motor muscles may be paralysed, sometimes alone, sometimes in association with limb

paralysis, and Roemer has reproduced the "jump" type in monkeys, and relapses occur as a rare manifestation as in man. In view, however, of the pathological finding of Kling, Pettersson and Wernstedt [64], who stated that a considerable number of their cases showed degenerative changes, it is important to study the clinical picture in their cases. That the clinical picture of experimental poliomyelitis may vary is shown by Leiner and von Wiesner, who have described a type of slowly progressive weakness in monkeys which they have designated as "marasmic."

Kling, Pettersson, and Wernstedt have divided the 116 monkeys who suffered from poliomyelitis into six clinical groups: (1) an upper limb, (2) a lower limb, (3) a mixed, (4) cerebral and bulbar type, (5) general muscular weakness, (6) "found dead." The first four groups are so well known and correspond to the usual type in man that no comment is necessary (except that in only one monkey did the illness commence with cerebral symptoms). With regard to the "general muscular weakness" which the authors use as synonymous with the "marasmic type" of Leiner and von Wiesner, it has no known counterpart as a clinical type in man.

The feature of this "general muscular weakness" group is weakness without localized paresis, and the authors state that they have found the disease manifesting itself in this manner in no fewer than twenty-six out of the 116 cases.

A monkey (No. 140) inoculated on November 1 was noticed on November 16 to be more slow in its movements. By November 20 it moved somewhat joltingly, but was otherwise well, possibly weak in the fore-limbs on November 25. It has during the past days been huddled up in one spot, and to-day is lying at the bottom of the cage and moves very little. It died on this evening.

Microscopical examination showed marked hyperæmia and hæmorrhages, but no cellular infiltration. Some of the glia cells distinctly enlarged. The ganglion cells generally dark and rather homogeneous, some of them being besides shrunken and vacuolated, enlarged glia cells often having eaten their way into them; the changes, however, on the whole, not very pronounced.

The clinical picture differs considerably from that which is usually accepted as that of poliomyelitis, as do also the pathological findings. The question might well be asked, Is this disease poliomyelitis?

Flexner, Clark and Fraser [58] are unwilling to accept these pathological findings as evidence of poliomyelitis because similar lesions have

not been shown to be present in fatal cases of poliomyelitis in man and because the organs of monkeys showing such lesions were only occasionally reinoculable and did not cause in the second generation in monkeys characteristic histological effects.

(9) *Pathological Changes found in Experimental Poliomyelitis.*

Most observers agree that the histological changes characteristic of epidemic poliomyelitis are similar in man and monkey. The lesions consist of necrosis and degeneration of the ganglionic nerve cells, with œdema, hæmorrhage, and leucocytic infiltration of the ground substance, the sheaths of the blood-vessels and the membranes.

Wickman believes that the virus produces both interstitial and parenchymatous lesions; Leiner and Wiesner think the virus attacks the parenchyma of the nervous system primarily, and the interstitial changes are secondary.

Flexner, from his histological study of spinal cords in the pre-paralytic stage of the experimental disease, shows the important fact that the interstitial changes are well advanced while the nerve-cells present a normal appearance. He points out the almost constant infection of the intervertebral ganglia in both human and experimental infection by inter-cellular invasion from the periphery to the centre, and comes to the conclusion that the virus acts chiefly upon the interstitial element of the meninges, causing a cellular, chiefly lymphocytic, accumulation, most abundant about the blood-vessels through which various parenchymatous cells become injured and destroyed.

Kling, Pettersson and Wernstedt [64], from their extensive series of experiments, describe two distinct pathological conditions in the monkeys dead of poliomyelitis: the one interstitial, the other parenchymatous :—

(1) The infiltrative type, the pathological picture commonly presented by the spinal cord of monkeys in connexion with experimental poliomyelitis.

(2) The degenerative type, in which cellular infiltration is absent and the striking change is degeneration of the nerve-cells. This degeneration affects not only the nerve-cells, but also the cells of the glia. The authors describe, in fact, two degenerative types: *the one* in which the ganglion cells are encroached upon by a large number of cells which are polymorphonuclear leucocytes and polyblasts, the polyblasts being, according to Wickman, the real neuronophages; *the second*, in which a cell having a large, clear, rounded cell-body eats its

way into the ganglion cell. This the authors designate as "glia-cell neuronophagia."

An important point is the proportion between the cases in which infiltrative and degenerative changes have been observed in experimental animals.

The figures show that animals inoculated from virulent cases give a far greater percentage of infiltrative cases than those inoculated from abortive and convalescent cases:—

	Animals dead	Infiltrative	Degenerative
(1) Typical cases	59 ..	25 (42 per cent.) ..	34 (58 per cent.).
(2) Abortive and virus carriers ..	34 ..	1 (3 ,,) ..	33 (97 ,,).
(3) Convalescents..	23 ..	2 (8 ,,) ..	21 (91 ,,).

The greater virulence and the appearance of the inflammatory infiltration evidently go hand in hand in the monkey. The authors come to the conclusion that the degeneration of the ganglion cells, as well as the cellular and humoral exudation, are to be regarded as the result of a direct injurious influence of the virus. This is a new light in which to regard the action of the virus of poliomyelitis, for in the past the changes in the nerve-elements have been regarded as secondary to the infiltration of the tissues. Further experiments are necessary to confirm or disprove the view expressed by these authors.

The view held by most experimenters is that the changes found in the brain and spinal cord in experimental poliomyelitis do not differ from those found in natural infection. In the spinal cord the lesions are usually more severe and widespread than in the brain. The meninges usually show a more or less diffuse infiltration with round cells. The layers immediately next to the white matter of the cord tend to show more cells than the layers next the dura mater. The greatest accumulation of cells is about the arteries and veins, the sheaths of which are surrounded by cells. The effect of these cells on the lumina of the smaller vessels is considerable. The meningeal cellular invasion is only interstitial, and does not give rise to an exudate upon the surface of the cord or brain such as occurs in acute exudative inflammation.

In concluding this digest of the experimental work, I have endeavoured to put before you the present view of the subject taken by the American and Continental schools. Many questions have been answered, but there are others which are still debatable, and one of the most important is that raised by the clinical and pathological picture produced by Kling, Pettersson and Wernstedt as the result

of these injections. Should their work be established, it will give to poliomyelitis an even wider clinical and pathological aspect than it has acquired during the last decade.

Chapter IV.—"Poliomyelitis" in Animals.

Infection of Animals other than Monkeys and Apes.

Most observers have failed to transmit human poliomyelitis to animals other than monkeys and apes. Flexner and Lewis tried the horse, ox, pig, rat, cat, and rabbit; Levaditi and Landsteiner tried the rabbit, guinea-pig, young dogs, and sheep. Leiner and Wiesner tried young dogs, fowls, pigeons, and rabbits; and Roemer rabbits, guinea-pigs, and mice—all without success [70].

Krause and Meinicke, Lentz and Huntemüller assert that they transmitted poliomyelitis regularly to rabbits. These rabbits succumbed with or without paralytic symptoms, and on histological examination the characteristic changes of poliomyelitis, more or less pronounced, were found. These investigators think that the inoculation into rabbits of cerebrospinal fluid, blood, brain, or spleen obtained from human cases of poliomyelitis leads to the death of these animals, and the inoculation of similar tissues obtained from rabbits that have succumbed into other rabbits will bring about their death. When the injections were made into the blood and peritoneal cavity a greater number of positive results were obtained than when they were made into the brain. The effects could be produced in rabbits, not only with an emulsion of the organs mentioned, but also with Berkefeld filtrates prepared from them. Levaditi once succeeded in transmitting poliomyelitis to a rabbit, and the spinal lesion was even more marked than in a monkey.

Marks [78] has further investigated this question. He used young rabbits; these were injected with an emulsion of the spinal cord from a poliomyelitic monkey; 2·5 c.c. to 3·5 c.c. of the emulsion was injected intravenously and intraperitoneally. The injection had no immediate effect on the rabbit. Some of the animals injected died between the eighth and fifteenth days after injection. When death occurred the symptoms came on suddenly, the final stage being generally ushered in by convulsions and rigidity, and death took place in from ten to thirty minutes after the onset of the symptoms. The post-mortem examination showed hyperæmia of the cortex, but no other striking lesion; and microscopical examination failed to show any further characteristic change. Other rabbits were injected with emulsions from various

organs of the rabbits which died, and some of these rabbits succumbed. The virus was thus passed through a series of six rabbits. From rabbits in the second, fourth and sixth set of the series of rabbits, monkeys were inoculated, and these monkeys all developed typical poliomyelitis.

These results leave no doubt that poliomyelitis can be propagated in certain individual rabbits, and that the virus is not confined to the central nervous system, but occurs in equal amount in other organs. It is probable also that not all strains of the virus can be transmitted to even a small fraction of individual rabbits, and this may account for Roemer and Joseph's failure in a long series. It is thus established that the virus of poliomyelitis can survive and probably be propagated in domestic animals that do not show any of the symptoms of poliomyelitis as it occurs in man.

Roemer [70], who has carried out a large series of experiments on rabbits, does not believe that they are a suitable animal for the investigation of poliomyelitis. He says thirty-one rabbits in four series received large doses of material containing the virus of poliomyelitis by simultaneous intravenous and intraperitoneal injection. The virulence of the material used was proved by the fate of the four control monkeys, which all died of typical poliomyelitis.

Of the thirty-one rabbits, thirty remained well for four months under daily observation, one animal suffered from an atypical form of paralysis, for which no lesion of the nature of poliomyelitis could be made responsible.

The similarity of the virus and of the pathological lesion of poliomyelitis and that of rabies, a disease of which the carrier species is known to be canine, suggest the possibility of some similar animal carrier for poliomyelitis. It is therefore important to investigate the paralyses of animals occurring at the same time as poliomyelitis in man, or of cases in animals presenting similar clinical features or pathological appearances. The simultaneous occurrence of paralysis in fowls and poliomyelitis in man has been noted by Krause, and he refers to other observations of the like nature. He failed to find any pathological lesion in the fowls investigated.

Lust and Rosenberg [74] carried out a series of experiments endeavouring to infect fowls, but they were unable to infect them either naturally or experimentally.

C. S. Shore, veterinary surgeon, refers to a disease appearing in one to two-year-old colts that showed a line of symptoms closely resembling poliomyelitis in children.

Reece, in his report on the epidemic of poliomyelitis in Devonshire, referred to the affection of pigs, to poke-neck in horses, to an affection of fowls, and to the death of a bull and a calf. No pathological examination was made in these cases. He also refers to a large mortality in Sweden of reindeer, poultry, and dogs from a disease stated to be poliomyelitis.

Roemer [79], in 1911, described a disease like poliomyelitis which arose spontaneously in guinea-pigs. The disease was due to an ultramicroscopic organism, which could withstand the action of glycerine and could be transmitted from guinea-pig to guinea-pig by intra-cerebral injections. Monkeys were not, however, susceptible to the disease, and though in its characteristics it closely resembled poliomyelitis, yet it is clear that it is distinct from that disease.

McGowan and Rettie [76] described poliomyelitis in sheep suffering from "loupin ill" and changes in the central nervous system similar to those found in poliomyelitis, but they were not able to transmit the disease by inoculation.

Holmes and myself [71], 1908, have described perivascular lymphocytosis and changes in the central nervous system of a dog which suffered from paralysis, and in 1913 Flexner and Clark [73] described paralysis in a dog simulating poliomyelitis. They were not, however, able to transmit the disease to other dogs by intraspinal inoculation.

Borna disease in horses, again, has a similarity, both clinically and pathologically, to poliomyelitis.

Marchant and Petit [77] describe a case of acute poliomyelitis with symptoms like Landry's disease in a mare. The animal died on the seventh day of illness, and the spinal cord showed foci of inflammation and degeneration of the ganglion cells. No micro-organisms were found. A guinea-pig inoculated with the blood of the mare died on the third day, but the examination showed nothing definite.

McGowan and Dawson [75] compare the lesion of the nervous system in distemper of the dog with those of human poliomyelitis, and come to the conclusion that they are strikingly similar.

The failure to communicate the diseases to monkeys, and in some cases even to animals of their own species, makes it almost certain that the diseases described in animals are distinct from poliomyelitis of man, though bearing some resemblance both clinically and pathologically.

Bruno [72] brought forward evidence of infection from ducks, and the simultaneous appearance of paralysis in a cow and goat.

The relationship of the diseases in animals to those in man is a question which needs most careful investigation.

Chapter V.—Serum Diagnosis.

(1) *Experimental method.*—Levaditi and Landsteiner and Müller have shown that it is possible to test the serum of patients and monkeys for their viricidal properties. For this purpose a 5 per cent. emulsion of the spinal cord containing the active virus is mixed with an equal quantity of the serum to be tested. The mixture must be made at a temperature of 34° C., and stood at room temperature for several hours. It is then injected intra-cerebrally in quantities of 0·6 c.c. to 0·8 c.c. into a normal monkey. A control monkey receives the same quantity of the virus. The control monkey becomes infected, the other monkey remains free. This experiment has been tried with the blood of a patient who has had herpes zoster, but the experiment was inconclusive, as the control monkey was not affected (Müller).

Anderson and Frost found that the blood serum, in six out of nine suspected cases of abortive poliomyelitis, was viricidal against the virus of the poliomyelitis. Landsteiner, Levaditi, Leiner and Wiesner have all shown that the serum is viricidal *in vitro*, but not *in vivo*. The serum injected into animals has no preventive or curative effect. The sera of animals has no viricidal power.

(2) *Fixation of the complement method.*—This point has been investigated by Wollstein, Roemer, Joseph, Levaditi and Landsteiner. All these observers agree that the use of an extract of organs containing the virus as antigen does not permit the discovery of antibodies in the serum or cerebrospinal fluid.

Roemer and Joseph call attention to the fact that this absence of amboceptor is similar to that in rabies, for no amboceptor has been demonstrated in that disease.

Peabody, Draper and Dochez carried out a series of tests with blood sera from—(1) normal persons; (2) from those exposed to infection in the ward or suspected abortive cases; (3) from typical cases, the serum from the patients being mixed with a known dose of the active virus incubated for one to two hours at 37° C., and allowed to stand in ice for twenty-four hours. The injections were then made intra-cerebrally into monkeys. The result was that the sera of the typical cases protected the monkey, but the sera from the normal and abortive cases gave uncertain results. So far no serum test, other than the above, has been devised. Such a test would be of the greatest value, for it would serve to render clear the nature of many cases of certain nervous diseases in children, the cause of which at the present time remain obscure.

Chapter VI.—Clinical Features.

(1) *Forms of Poliomyelitis.*

Recognizing that poliomyelitis is an acute infective disease which may attack any portion of the nervous system, it is at once apparent that the clinical picture may be most varied according to the situation of the lesion. Many observers have collected and tabulated their cases according to the part of the body paralysed, and it has been shown that the legs, and especially the distal muscles, are more commonly affected than any other part. Isolated paralysis of the trunk muscles occurs in about 1 per cent., and isolated paralysis of the cranial nerves in about 2·5 per cent. Wickman's figures show that in 68 per cent. of all cases the legs are affected. Wickman divided the cases into various groups on an anatomical basis, according to the portion of the nervous system involved. The groups are as follows :—

(i) The spinal form.
(ii) The bulbar, pontine and mid-brain form.
(iii) The cerebral form.
(iv) The cerebellar form.
(v) The meningitic form.
(vi) The neuritic form.
(vii) The abortive form.

Peabody, Draper and Dochez [107], in their excellent monograph on the clinical features of poliomyelitis, criticize this classification, saying that it is based neither on pathological anatomy nor on clinical symptomatology, but on a mixture of the two. They prefer the classification suggested by Müller on an anatomical basis—viz. :—

(i) Spinal form.
(ii) Bulbar form.
(iii) Cerebral form.
(iv) Abortive cases.

But even here a clinical type (abortive cases) has to be introduced to complete the classification. No other classification seems to me to be so helpful in the clinical description of the disease as that given by Wickman.

(i) *The Spinal Form.*

This is the common manifestation of the disease, and the type most usually seen is that of a flaccid paralysis of one or more limbs; sometimes all the muscles of both limbs, trunk and neck are completely paralysed. The clinical variations in this form are, however,

considerable and require special notice, for they are not always recognized as manifestations of poliomyelitis.

Ascending and descending type: A type which is not common, and is more frequently seen in adult life than in childhood, is the ascending type (sometimes called Landry type), in which the disease, starting from below, gradually ascends and affects successively the legs,

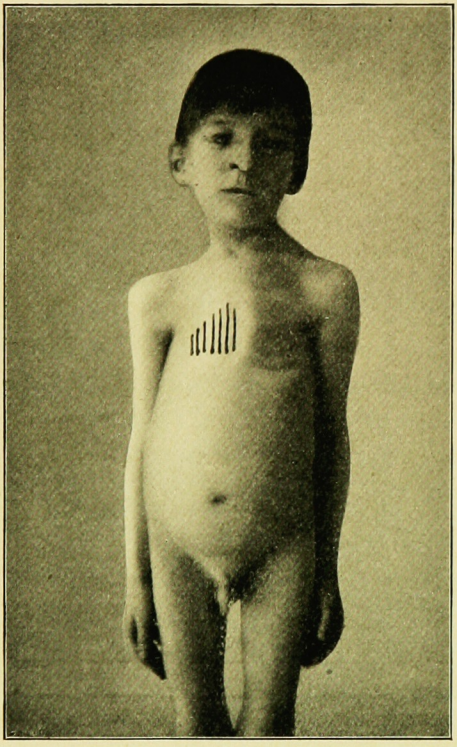


FIG. 24.—Photo of a boy with paralysis of the intercostal and abdominal muscles and complete collapse of the right lung due to poliomyelitis. The heart is displaced to the right side, as indicated by the shaded area on the chest wall.

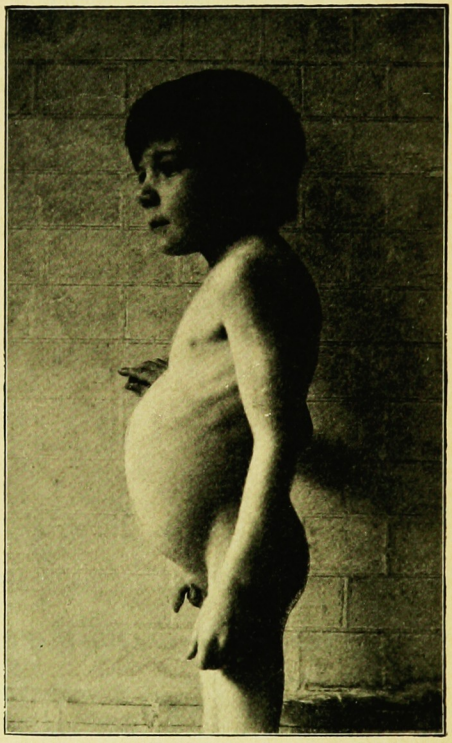


FIG. 25.—Lateral view of same case, showing the prominence of the abdomen due to weakness of the abdominal muscles.

the abdomen, the thorax, the arm and neck, so that eventually the respiratory centres are involved and the patient dies from failure of respiration, consciousness often being retained to the end.

This ascending progress of the disease is not always uniform; the disease after affecting the lower limbs, will sometimes cease, and then, after an interval of two to three days or it may be even ten to fourteen,

again start its upward course, possibly again become arrested for a time, and then make further progress until the respiratory centre or the bulb becomes involved. These have been designated the "jump" cases, and experimentally similar manifestations have been noted by Roemer in the monkey [50], and he refers to a similar instance reported by Levaditi and Stanesco.

Sometimes the disease will manifest itself first in the upper segments of the cord, and involve the lower limbs at a later period (descending type).

Thoracic and abdominal type: Sometimes the disease will involve the thoracic and abdominal muscles alone, leaving the limbs unaffected, and in such a case the acute respiratory disturbance suggests the onset of pneumonia. This is intensified when accompanied by complete collapse of one lung. It is difficult to say whether the collapse of the lung occurs at the same time as the paralysis of the intercostal muscles or is due to the blocking of the bronchus by mucus which there is no expiratory effort to expel.

The following case illustrates this condition (fig. 24) :—

A. H., aged 4, taken ill in August, 1914, with "pneumonia." Six weeks later he was admitted to the hospital with complete paralysis of the intercostal and upper abdominal muscles, but without any marked affection of the limbs. He had complete collapse of the right lung, and the heart was displaced to the right side. Endeavours were made to expand the right lung without success, and eighteen months later the condition of the lung was unaltered, and the heart in the same position. Respiration is carried on entirely by the diaphragm.

Sutherland [113] has described a similar case in an infant, aged 15 months, with paralysis of the abdominal muscles and collapse of the right lung.

Abdominal muscles: Paralysis of the abdominal muscles frequently accompanies that of the intercostals. The weakness of these muscles gives rise to difficulty in rising from the lying into the sitting position, and to a marked prominence when the patient assumes the erect position (fig. 25). During inspiration it is not unusual to see marked recession of the epigastrium. It is not uncommon to see a partial paralysis of the abdominal muscle, so that when the child coughs or strains there is a protrusion of the abdominal contents into the thinned abdominal parietes, and such a protrusion suggests to the parent that a tumour is growing in the abdomen (fig. 26). Although paralysis of the abdominal wall most frequently occurs in association with thoracic and limb paralysis,

yet it may be absolutely limited to a small portion of the abdominal or oblique muscles, and be the only manifestation of a past poliomyelitis.

Weakness and paralysis of the dorsal muscles of the back prevent the child from assuming the erect position either when sitting or standing. The trunk falls forward and the child is unable to erect it. Such a weakness often gives rise to the saddle-back and to the quadruped walking

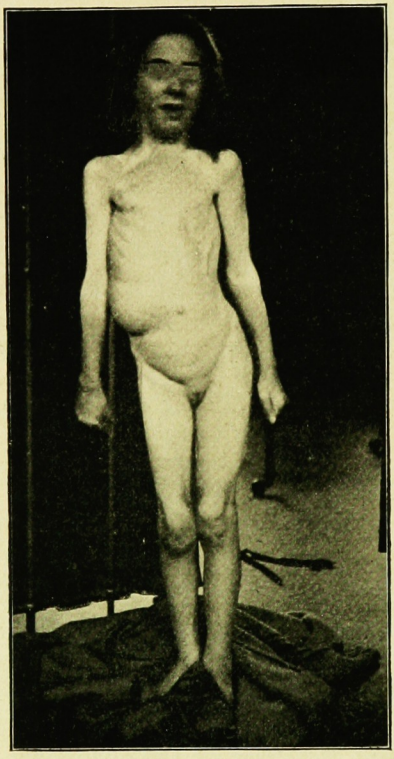


FIG. 26.—Photo of girl, showing local bulging of the abdominal wall due to poliomyelitis. (For this photograph I am indebted to Dr. Sutherland.)

adopted by these children as a mode of progress (fig. 27). It is the weakness of these muscles which gives rise to the most marked lateral curvatures.

Transverse lesion: A somewhat rare manifestation of acute poliomyelitis is a transverse lesion of the spinal cord, so that the patient has complete flaccid paralysis of both legs, loss of sphincter control, and loss of sensation to the level of the lesion. This lesion may remain complete, or may clear up, leaving the patient with spastic paraplegia

with increased knee-jerk, ankle clonus, and defective control over the bladder. As illustrative examples the following cases may be quoted :—

F. T., aged 19, was taken ill January, 1914, with fever and pains, and with a rapidly progressive paraplegia which became complete in forty-eight hours, giving rise to an absolutely flaccid paralysis of both legs with loss of sensation to a line 1 in. above the umbilicus. There were retention of urine and an absence of all the deep reflexes. About six weeks later the knee-jerk returned, and eventually both legs became spastic. Sensation also began to return. The examination of the blood and cerebrospinal fluid excluded syphilis. The possi-

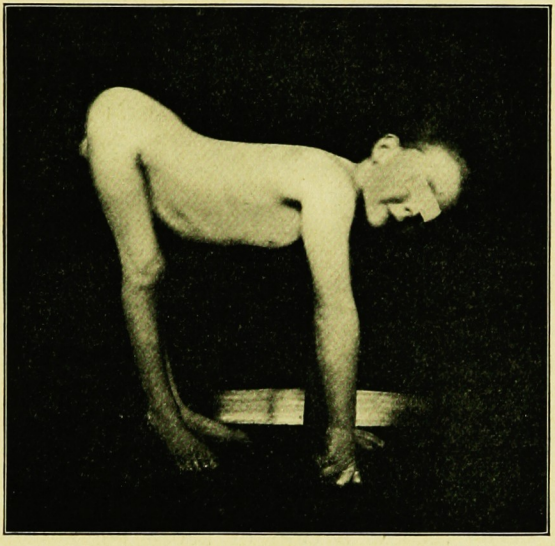


FIG. 27.—Boy with extensive poliomyelitis, especially of the extensors of the thighs on the trunk. He was unable to maintain the erect position, and adopted the quadruped method of walking.

bility of an extradural hæmorrhage and tumour was excluded by operation, which revealed a cord presenting almost a normal appearance. The girl, after eighteen months, recovered some power in the legs, but was left in a very spastic condition.

J. D., aged 6, was taken ill on May 2, 1915, with convulsions, fever, pains in the back, and weakness of both legs and arms. The sphincters were affected. He was admitted to hospital August 6, 1915. He had then a very spastic condition of both legs, with considerable adductor spasms and very little power of movement. The knee-jerks were increased, there was ankle clonus on both sides, and the plantars were extensor. No alteration in sensation could be detected. The cerebrospinal fluid was normal, and both blood and cerebrospinal fluid gave a negative Wassermann. The X-rays

showed there was no disease of the vertebræ. On August 14 he developed measles, and during his convalescence therefrom the power in his legs began to improve, the improvement being maintained, so that when he left the hospital on October 25 he could walk fairly well, but was still spastic.

When the lesion is situated in the cervical region, weakness and wasting of the hand and arm muscles, and a spastic condition of the leg, may occur :—

E. D., aged 2, was taken ill in July, 1913, with a rise of temperature, profuse sweating and great pain and screaming attack; his illness was attributed to a circumcision which had recently been performed. After recovering from the acute attack, which lasted about seventeen days, it was noticed that he could not move his hands, and was very weak in the legs and back; it was also noticed that his knee-jerks were brisk and ankle clonus was present. When seen in October, 1913, there were marked weakness and wasting of the small muscles of both hands, drooping of the eyelid (probably due to sympathetic affection), a spastic condition of both legs with increased knee-jerks, ankle clonus and extensor responses; no sensory defect. The X-rays showed no disease of the cervical vertebræ. The boy slowly improved, but two and half years later still had marked weakness of the small muscles of the hand and a spastic condition of the lower limbs.

It is admittedly difficult in the cases like those above quoted to give positive proof that the lesions were due to the virus of poliomyelitis, for such cases rarely die, so that pathological and experimental evidence is wanting. It has not been possible to carry out the serum test. But by excluding the common causes of transverse lesion one is justified in suggesting that poliomyelitis may be the causal factor.

B. Sachs [110] records a case of acute poliomyelitis in a girl, aged 18, with sudden onset of complete flaccid paralysis and loss of sensation to the xiphoid with complete recovery in two months. The cerebrospinal fluid showed a high lymphocytic count.

Netter and Levaditi [103] report four cases presenting symptoms of transverse myelitis which they attribute to the virus of poliomyelitis. They were able to show that the blood of a patient who had recovered possessed the properties for neutralizing the virus of poliomyelitis.

Strümpell [112] records a case in a man, aged 19, of sudden onset of paralysis of the arms with considerable loss of sensation in the trunk and leg below the seat of the lesion. This lesion he attributes to poliomyelitis. Similar observations have been made by others.

Abnormal attitudes assumed in incomplete paralysis : When all the muscles of a limb are involved a complete flaccid palsy results, and no abnormal attitude is assumed or deformity produced; but in many

instances certain groups only are involved, and the contraction of the unbalanced antagonistic muscles gives rise to unusual position and deformities. The two following cases illustrate this point. They must, however, be considered rather unusual manifestations of the disease. The first is that of a child in whom the extensors of the right thigh were completely paralysed, whilst the flexors were unaffected, the result being that the leg was held erect in the air as the child lay in bed (fig. 28).

In the less extreme examples of this form the leg is held out in front, and gives rise to a difficulty in walking quite out of proportion

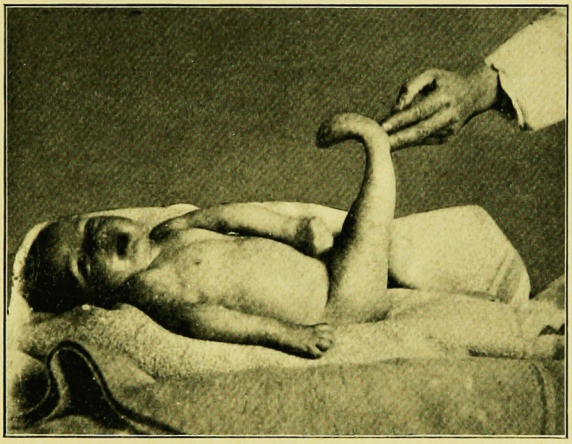


Fig. 28.—Infant with poliomyelitis of both legs and arms, the right leg is held erect in the air owing to the paralysis of the extensors of the thigh and the unbalanced contraction of the flexors. The leg is being steadied by the hand of an observer for photographic purposes.

to the weakness of the limb, and the attempt to bring it into line with the trunk only produces a lordosis, or the trunk is bent forward with a loss of balance. When this deformity is bilateral the lordosis becomes marked, and the child can only assume the erect position by an extreme lordosis of the spine (fig. 29).

The reverse of the above condition is seen in the case of a child in whom the flexors of the thigh are paralysed, whilst the extensors are unparalysed and in active contraction. Such a condition gives rise to a rigid child, the legs cannot be flexed and the child can be supported by the head and heels, and held out in a rigid position such as shown in fig. 30. The case is as follows :—

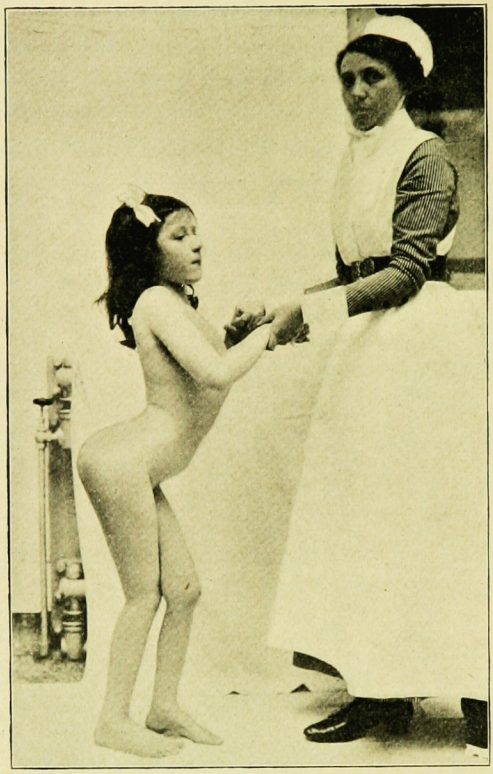


FIG. 29.—Girl with extensive poliomyelitis and bilateral contraction of the flexors of the hip-joints.
In the attempt to assume the erect position a lordosis of the spine is produced.

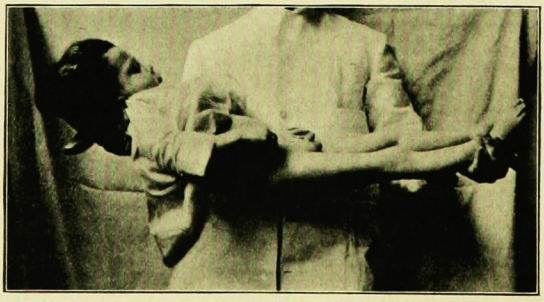


FIG. 30.—Child with extensive poliomyelitis, showing rigid extension of the hips, due to the unbalanced action of the gluteal muscles. This rigidity was such that the child could be supported by one hand placed under the head, and the other under the heels.

Poliomyelitis with rigid extension of the legs at the hips : H. G., the fifth child of a family of five, was taken acutely ill with poliomyelitis in September, 1912, the limbs, trunk, face and eyes being affected at the onset. He was acutely ill for fourteen days, then gradually recovered the power in his right arm, but had severe pain and tenderness in trunk and lower limbs. When seen in March, 1913, both legs were rigid at the hips and everted, and attempts at movement caused acute pain. Below the knee the muscles were flaccid and the feet in a position of equinus. The shoulder muscles of the left arm were completely paralysed, and there was likewise considerable intercostal and abdominal paralysis. The child was quite rigid in the extended position, and if lifted off the bed by one hand placed under the head and another under the heels, he maintained this extended position (fig. 30). This rigid extension of the hips appeared to be due to the unbalanced action of the gluteal muscles, the psoas and the iliacus muscles being completely paralysed. Any attempt at flexion of the hip gave rise to pain, but if once flexed, the hip-joint could be moved in any direction quite easily. X-ray examination made it certain that there was no hip disease. All the deep reflexes were abolished in the lower limbs. The pain on movement in this case persisted for over fourteen months. In this case the child was up in plaster of Paris in a position of flexion, so as to overcome the extension and allow the flexors to recover. Although the child was kept for months in this position, yet he always, in a few days after the plaster was removed, reverted to the rigid extended position. It is interesting to note that when first taken out of plaster the legs remained in the flexed condition for a few hours. Massage, movements, hot baths, had no effect, either in overcoming the rigidity or of removing the pain on movement.

Paralysis of neck muscles In some cases the neck muscles may alone be affected, so that the head flops about in all directions. In one case the affection was almost limited to the neck muscles, the shoulder muscles being but slightly affected, whilst the muscles supplied by the bulb escaped entirely; the diaphragm, too, was unaffected (fig. 31) :—

William F., aged 11, was taken acutely ill in March, 1915. He had severe headache, vomiting and constitutional symptoms ; one week after onset a measles-like rash appeared which lasted two days. He had, when seen ten days after the onset, some weakness of shoulder muscles and complete flaccid paralysis of the neck muscles, being quite unable to hold the head up. He at no time had any bulbar symptoms. He could move the arm well and had full power in the thoracic, abdominal, and leg muscles. He was quite unable to sit up or walk, owing to the weakness of his neck muscles. The cerebrospinal fluid was clear, contained 0·15 per cent. albumin, no cells, and gave a negative Wassermann reaction. The neck was splinted (*see* fig. 43), and the boy gradually recovered power, but considerable weakness of sterno-

mastoid and trapezius remained. He could walk quite well as long as his head was supported by the splint.

Unilateral paralysis of the diaphragm: The diaphragm may be affected at the same time as the intercostal muscles, and sometimes one

FIG. 31.—Boy with complete flaccid paralysis of neck muscles, those supplied by the bulb escaped entirely (compare fig. 43), and the limb muscles almost entirely.

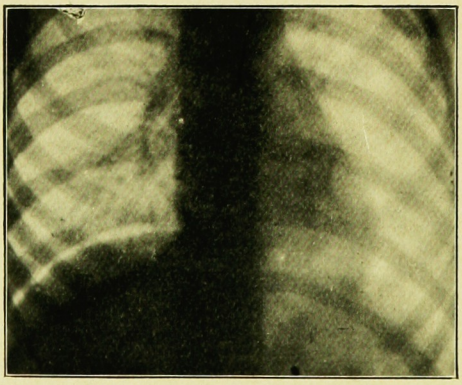


FIG. 32.—Unilateral paralysis of the right side of the diaphragm (from an X-ray kindly lent by Dr. Voelcker).

side of the diaphragm is involved whilst the other moves well. This is best seen on an X-ray screen, when the movements can be watched (fig. 32).

Sympathetic paralysis : Paralysis of the sympathetic fibres has been noted in cases of poliomyelitis in the region of the first dorsal and lower cervical segments of the cords, but no observations have been made on the occurrence of subnormal temperature such as is known to occur and has recently been noted by Gordon Holmes in the Goulstonian Lectures in injury to the lower cervical region of the spinal cord.

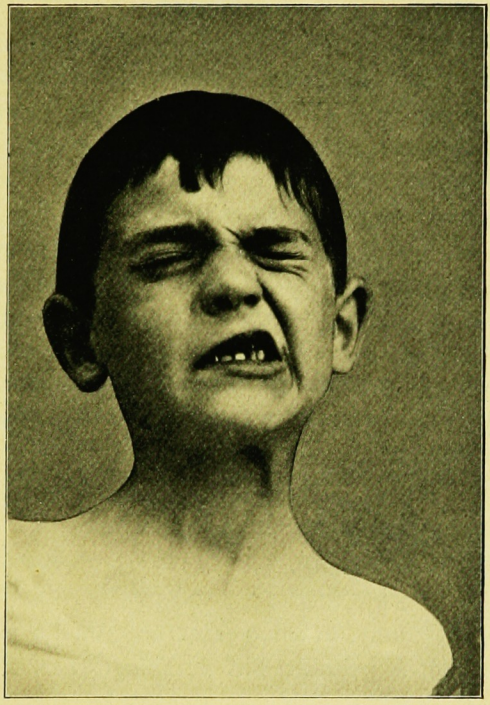


Fig. 33.—Paralysis of the right side of the face, associated with flaccid paralysis of the muscles of the right shoulder.

(ii) *The Bulbar, Pontine and Mid-brain Form.*

Bremer [85], in an analysis of 400 cases of poliomyelitis from the records of the Children's Hospital, found that forty-eight—i.e., 12 per cent.—showed some evidence of an encephalitis, facial paralysis being the commonest manifestation, whilst ataxia, nystagmus and tremor formed the next most numerous group. The clinical manifestations exhibited by lesions in this region are most varied. Any extensive lesion in the bulb is almost always rapidly fatal, and a typical instance of such with a good pathological examination is recorded by Feiling [90].

The acute symptoms may be severe, yet they will often clear up, leaving a paralysis limited to one or more cranial nerves.

Lesions in this region may affect any one or more of the cranial nerves; that which is most commonly attacked is the seventh, giving rise to a facial paralysis of the lower motor neuron type (fig. 33). When such a paralysis is associated with a poliomyelitic lesion in the cord, causing a limb paralysis, or when another member of the family is affected with the ordinary type of poliomyelitis at the same time, it is not difficult to recognize the nature of the affection; but when the facial paralysis occurs as the solitary manifestation, considerable difficulty arises in regard to the diagnosis. It has been noted that the number of cases of facial paralysis among children tends to increase with the prevalence of poliomyelitis.

Of the other cranial nerve nuclei, those supplying the tongue, the palate, the masseter and temporal muscles may be affected, either unilaterally or bilaterally. The oculo-motor nuclei may be affected, giving rise to a complete or partial ophthalmoplegia. Blindness is sometimes associated with the paralysis. Return of vision and complete restoration of power in the muscles may take place, or the ocular palsy may clear up, leaving the child completely blind. I have recorded such an association in a child:—

M. S., aged 5½, taken ill acutely with headache, followed by loss of sight and complete ophthalmoplegia externa; the opthalmoplegia cleared up almost entirely in a month, leaving the child, however, completely blind. There was slight swelling of the disk, but not a marked optic neuritis.

That poliomyelitis may, in some cases, account for the sudden loss of vision and of hearing is possible, but pathological confirmation has not been obtained.

Associated myelitis and optic neuritis: E. Clowes [86] records a case of acute myelitis with optic neuritis in which the sudden onset, the character and progressive nature of the symptoms, with death on the fourteenth day of illness, strongly suggest the possibility of poliomyelitis as the causative factor. Unfortunately no pathological examination was obtained.

Dr. Frederick Taylor [114] alludes to the association of optic neuritis with spinal lesion, of which there are a number of recorded instances. Many of these cannot be attributed to poliomyelitis. It is, however, the acute and sudden onset of both spinal and ocular symptoms which is the feature which so strongly suggests the poliomyelitic infection.

Hertz, Johnson and Depree [96] record the case of a boy, aged 12½,

who had acute onset of paralysis with optic neuritis and ocular palsy. The cerebrospinal fluid showed lymphocytosis and polymorphonuclear cells in almost equal numbers. The boy recovered to a very considerable extent. The authors regard this as a case of polio-encephalo-myelitis.

Mid-brain lesions: The symptom most characteristic of lesions in mid-brain is that of a rhythmic tremor of the limbs associated with an ocular and sometimes other cranial nerve paralyses. Holmes has described the tremor of mid-brain lesion as a slow regular tremor, increased by involuntary movement and by excitement. It may be universal and affect the whole body, but in most cases is limited to the limbs and is seen in its most typical form in the arms. There is an increase of tone and some disability in using the limb, but there is no true spasticity, and the limb is in a condition of "plastic tone." As illustrative of this condition the following case, recorded by Leonard Parsons [106], may be quoted:—

A girl, aged 2, was at play and apparently quite well on the evening of July 15. She was put to bed and noticed to be feverish. At 10 p.m. she had a fit, became sleepy and unconscious. At 10 a.m. and 12 noon she had a recurrence of the fits. On recovering consciousness it was noticed that she was trembling all over; the tremor affected the tongue, arms, legs and trunk, and was exactly like shivering. For three weeks she remained in bed, during which time the tremor persisted; she was apparently conscious, took her milk, but her eyes were fixed and staring and she did not appear to see anything, nor did she speak. When admitted to hospital on August 2, there was slight retraction of the head, her expression was staring and she was apparently quite blind. There was present a slow, rhythmic tremor of the arms with marked rigidity of the limbs, but no evidence of paresis. The knee-jerk and abdominal reflex were present, and the plantar responses were flexor. Both pupils reacted to light, and the fundi showed no change. There was broncho-pneumonia. The cerebrospinal fluid was examined and no lymphocytosis or organisms were found. On August 24 the child spoke for the first time, and it was noticed that her vision had returned. On September 4 the tremor was no longer present whilst the child was at rest, but was brought out by voluntary movement. She left the hospital on September 12, but she still had some tremor on voluntary movement. She was seen again in February, 1910, when she appeared well and talked freely.

Other cases occur in which ocular palsy and nystagmus are present, and others again in which there is evidence of involvement of the fifth, sixth and seventh cranial nerves, the variation in symptoms depending on the situation and extent of the lesion.

It may be well to mention here the movements which Netter and Ribadeau-Dumas [104] describe as chorea occurring before and during

the onset of acute poliomyelitis, and these are probably of the same nature as those described by Colliver [87] under the name "A pre-paralytic symptom in acute poliomyelitis" as a tremor and convulsion of certain groups of muscles.

(iii) *Cerebral Form.*

The most characteristic feature of this type is hemiplegia. The onset of the illness is sudden, associated with convulsions, which may be unilateral or bilateral, and loss of consciousness, and the child, on recovery, is found to be hemiplegic. Poliomyelitis is probably not a frequent cause of infantile hemiplegia. Of 100 cases of infantile hemiplegia collected by myself, only ten could on clinical grounds alone be ascribed to polio-encephalitis, the criteria for such being that the child was perfectly healthy before the onset, the onset was sudden, that it occurred during the summer months, and the symptoms were retrogressive after the attack was over, and that there was no cardiac or other condition likely to give rise to a hemiplegia.

Should the hemiplegia be associated with a poliomyelitis of the limbs, it may with reasonable probability be assumed that the lesions are due to the same causal organisms, and a striking instance of such an association has been published by Rossi [109], the diagnosis being verified by a pathological examination, to which allusion has already been made in the section dealing with pathology.

An American writer, Manning [99], tries to prove that the attack of hemiplegia from which Pasteur suffered at the age of 46 was due to a poliomyelitis—the infection being derived from the silkworm, Pasteur being engaged on that work at the time.

Athetosis of left arm and left side of face, flaccid paralysis of left leg, and some flaccid paralysis of right leg : The association of a hemiplegia with athetosis with a poliomyelitis is one of the rarest manifestations of the disease, and the following instance may be given :—

A. A., aged 7, was the seventh of eight children. She was a healthy baby till the age of 10 months, when she had an acute illness with convulsions. From this she recovered, but it left her with paralysis of the left side. She subsequently learnt to talk, was intelligent, and went to a school for physically deficient children. She never learnt to walk. When first seen she was a pale child, with marked athetosis of the left arm and involuntary movements of the left side of the face. She was unable to stand, and if an attempt were made to place her on her legs, she supported her weight on the right leg with the knee flexed, the left leg being too weak to support any weight. The left hand exhibited spontaneous movements of an athetoid character (fig. 34),

which were increased on attempting to walk or on any emotional stimulus. The child had little voluntary power of movement in the left hand; there was, however, no rigidity, and the hand, though at times strongly contracted, yet when moved passively was quite flaccid. The left leg showed the typical flaccid palsy of poliomyelitis with wasting of muscles, loss of deep reflexes, and loss of electrical reaction of all muscles below the knee, and to a lesser degree above the knee.

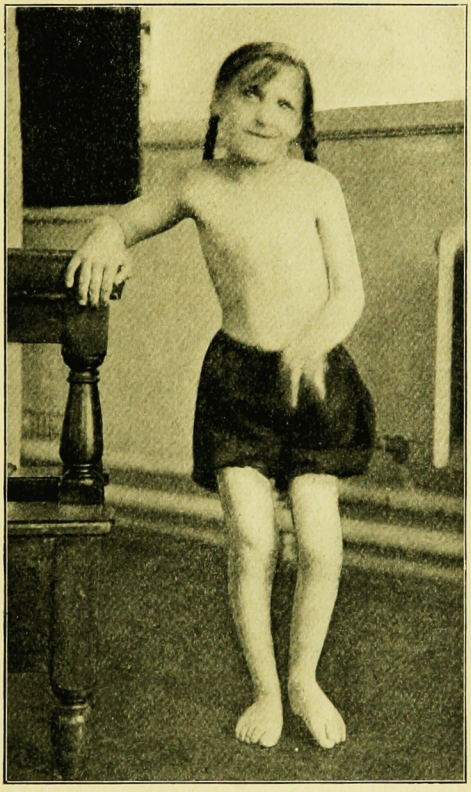


FIG. 34.— Athetosis of the left arm and left side of the face, associated with a flaccid paralysis of the left leg, and partial paralysis of the right leg.

This case illustrates the association of an athetosis with a poliomyelitis. There is no reason to doubt that the paralysis of the legs is due to a spinal lesion, and the athetosis of arm and face to a cerebral lesion. It may be questioned whether there is sufficient evidence to prove that the condition is the result of the virus of poliomyelitis, but, so far as the legs are concerned, they may be considered typical of the condition. The arm paralysis occurred at the same time, and there

seems no reason for hypothesizing another toxic condition for the production of the focal lesion in the brain. The contraction which was present in the legs has been corrected, and with support the girl walks fairly well. The athetosis of the left arm persists.

Mental defect: Cases in which marked mental defect persists after an acute cerebral attack in children are not uncommon, but the difficulty of proving that such cases are due to poliomyelitic virus is considerable. Such cases may or may not be accompanied by an alteration in the cerebrospinal fluid. When accompanied by a lympho-

FIG. 35.—Child with acute cerebellar ataxia attempting to walk. The nurse is preventing the child from falling backwards, a tendency which such cases commonly exhibit. Note the wide base and the spread arms.

cytosis the cases come within the meningeal group and are dealt with under that head, but those cases in which the fluid is perfectly normal correspond closely to those in which the poliomyelitic virus affects other portions of the brain and spinal cord, no change being found in the cerebrospinal fluid.

The cases of this type have always been isolated, and I have never seen this form in one member of a family in which others have typical poliomyelitis. Pathological proof of the nature of the affection has not been obtained.

(iv) *The Cerebellar or Ataxic Form.*

This type is characterized by the acute onset of ataxia, sometimes associated with ocular and other cranial nerve paralyses and alteration of articulation. Nystagmus is often absent. As with other forms of poliomyelitis, the onset may be attended by malaise and vomiting, but in other cases the onset is quite sudden, and the child having gone to bed perfectly well, is found in the morning to be wildly ataxic, but otherwise not ill. In some cases the ataxia clears up rapidly, so that after ten to fourteen days the child is quite well. In other cases it takes many months and sometimes years to clear up.

An interesting instance of slow and gradual recovery in a boy who, after an acute illness, was ataxic for some three years has been recorded by Dr. Frederick Taylor [115]. When seen some twenty-five years later he was in every respect a normal individual, and had been so during boyhood and manhood, having played the usual games necessitating good co-ordination.

The following is an instance of one child in the family being affected with the ordinary type of poliomyelitis and another with ataxia:—

Poliomyelitis and ataxia: probably due to involvement of the cerebellum: R. S., aged $5\frac{1}{2}$, and M. S., aged $1\frac{1}{2}$, are brother and sister, and they were both taken acutely ill within a week of one another on August 16, 1909. The elder child had left facial paralysis and ataxia of the right arm and leg, whilst his sister had paralysis of the left side of the face and flaccid palsy of the neck muscles. In the elder child the ataxia cleared up in about fourteen days after the onset of the acute illness. The paralysis of the face cleared up somewhat later. In the case of his younger sister the weakness of the face persisted for many months, as did also the weakness of the muscles of the neck, some permanent paresis of the neck muscles remaining. In these two cases there is no doubt that the paralysis was due to acute poliomyelitis, and in the case of the older child it seems probable that there was a focus of the disease in the cerebellum.

Numerous other instances of acute cerebellar ataxia might be quoted, some of which have cleared up rapidly, and others have persisted for months and years.

In those cases in which ataxia of sudden onset is the only symptom it may well be doubted if they are caused by poliomyelitic virus, but the same cannot be said of those cases in which the ataxia is seen in conjunction with other more usual manifestations of the disease, or in such cases as those in which one member of the family has definite poliomyelitis and another is affected with ataxia.

That the lesion is in the cerebellum also may be questioned, for there is but little pathological evidence on these cases, but as the clinical signs closely correspond with those seen in definite lesion of the cerebellum, there is little doubt that the lesion lies somewhere in the cerebellar path.

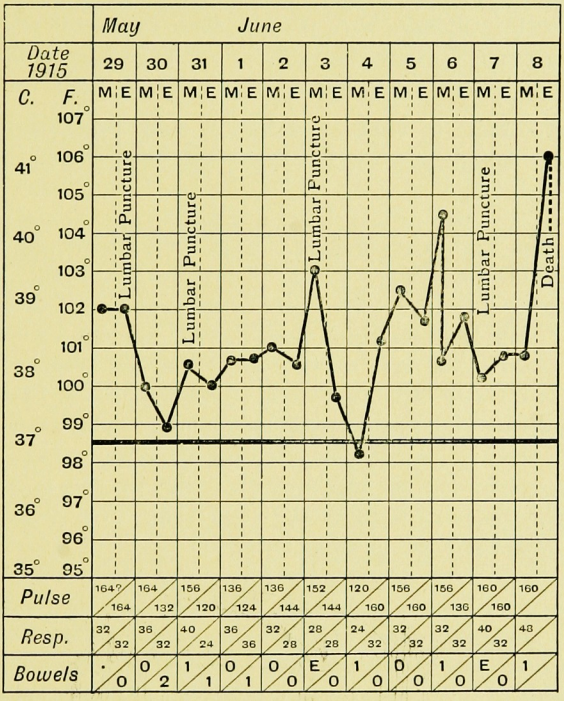
(v) *Meningitic Form.*

Possibly one of the most interesting groups of poliomyelitis, and one which frequently leads to an error in diagnosis, is the meningitic form of the disease. The onset may be sudden, attended by convulsions and coma. This may rapidly pass off, or persist and deepen. Temperature is raised and may remain high for days. The neck is stiff, and the legs rigid in a flexed or extended position, and Kernig's sign may be present. The pulse is slow or rapid, according to the stage of the disease. All the symptoms of a meningitis may be present, and on lumbar puncture the cerebrospinal fluid escapes under pressure, is clear, and on cytological examination may be found to contain an increased number of lymphocytes with a normal, or sometimes a diminished sugar reaction and increased amount of albumin.

The cases thus present the clinical picture and cytological condition of the cerebrospinal fluid which is of frequent occurrence in tuberculous meningitis. If tubercle bacilli are found in the cerebrospinal fluid the diagnosis is clear, but if not found the case falls into the group of lymphocytic meningitis from which recovery is possible. The causes of a lymphocytic meningitis are numerous, and from the examination of the cerebrospinal fluid alone it is not possible to be certain that one is not dealing with a serous meningitis associated with a sinus thrombosis, middle-ear disease, cerebral abscess; with that following mumps or measles; with that due to syphilis or an old and past infective meningitis or to poliomyelitis. As illustrative instances of the meningeal form the following cases may be quoted :—

G. Y., aged 3, was taken ill on June 30, 1913, with sore throat. He was feverish for two or three days. On July 3 he had pains in the back, he cried when moved, and the back was stiff. He was admitted to hospital on July 8 and then had marked retraction of the head and opisthotonos. Any movement of the neck in a forward direction gave rise to pain, but he would allow rotation. There was no rigidity of arms or legs, and the power was good, except in the left leg, which was completely flaccid. On lumbar puncture the cerebrospinal fluid was under pressure, was clear, contained 0·1 per cent. of albumin, no clot, and no cells. The rigidity of the back gradually passed off, but he was left with a flaccid paralysis of the left leg, which recovered to a very great extent after a year's treatment.

R. W. M., aged 5, a patient under the care of my colleague, Dr. Colman. Six weeks previously had measles, from which he rapidly recovered. He came home from school with headache May 26; in the evening he vomited. On the following day he had headache and frequent vomiting. He was feverish. On the morning of May 29 he became convulsed, was delirious, and no longer recognized his mother. He was admitted to hospital, and temperature was 102° F., pulse 164, respiration 32; he was semi-conscious, the neck was rigid, limbs rigid and extended. The cerebrospinal fluid was clear, under increased



Temperature chart of a case of poliomyelitis which presented symptoms similar to those occurring in tuberculous meningitis. Case proved to be poliomyelitis by microscopic examination.

pressure, contained no increase of cells and no albumin, and gave an immediate reduction with Fehling's solution. The condition progressed, the temperature remained high, the cerebrospinal fluid, examined on four occasions, first revealed no cells, then a few, and on the last occasion (June 7) were numerous and were lymphocytic in character; the fluid still reduced Fehling's solution. The boy died on June 8, fourteen days after the onset of the disease. At the autopsy there was no macroscopic meningitis, but on section through the crus and mid-brain marked engorgement of the vessels was found, and on microscopical examination a most extensive perivascular lymphocytosis was present. The spinal cord showed no change.

A third case is that of a boy, aged 4, who six weeks previously had had his tonsils and adenoids removed. He was taken ill on November 16; on November 17 he was feverish, passed into a comatosed condition, was admitted to hospital on the 18th and died on the following day. He was regarded as a case of meningitis, but the lumbar puncture revealed a blood-stained fluid from which it was not possible to make any deduction. *Post-mortem* examination showed extravasation of blood in the region of the cauda equina, possibly due to the lumbar puncture, otherwise the cord appeared to the naked eye normal. On microscopical examination, however, typical poliomyelitic changes were present, most marked in the medulla and in the wall of the fourth ventricle (fig. 18). No change was found in the cerebral hemispheres.

The fourth case is that of a child who presented symptoms of a lymphocytic meningitis with rapid recovery. The details are as follows:—

Betty B., aged 3, the only child of the mother's second family, was taken ill with an attack of vomiting on Friday, September 24, 1915. She was said to have "lost herself" and to have been queer ever since. Her spine seemed to give way and her head was bent to one side. She cried when disturbed and complained of pain at the back of the neck. She was brought to the Hospital for Sick Children, Great Ormond Street, on September 29, 1915, and admitted with the diagnosis of "posterior basic meningitis." On admission, she was a well-nourished child; did not look seriously ill. The temperature was 97° F., pulse 96, and respiration 24 per minute. She sat up in bed of her own accord but held the head towards the right side. On physical examination of the chest and abdomen nothing abnormal could be detected. All movements of the limbs were perfect, but there was slight stiffness of the head and neck and she resented movement. All the deep and superficial reflexes were normal; the optic discs were normal. Kernig's sign was not present. Lumbar puncture was performed and a slightly turbid fluid, just blood-stained, was obtained, which on examination was shown to contain 0·5 per cent of albumin, failed to reduce Fehling's solution, and contained a large number of cells, nearly all of which were mononuclear; no organisms were seen, and the culture on the placenta agar remained sterile; no tubercle bacilli were found. From the examination of the cerebrospinal fluid the most probable diagnosis would seem to be tuberculous meningitis. On October 1 a second lumbar puncture was performed. The fluid again was slightly turbid, formed no clot, gave no immediate reduction of Fehling's solution, contained 0·5 per cent. albumin and a large number of mononuclear cells. No tubercle bacilli were found. On October 8 the child could move the head and neck well and seemed almost normal. Lumbar puncture was performed and the cerebrospinal fluid appeared clear, had no clot, contained 0·125 per cent. albumin, gave *no* immediate reduction of Fehling, and contained a fair number of mononuclear cells (lymphocytes). Cultures on agar were sterile and on placental agar

anaerobically after three days gave two colonies of *Staphylococcus albus* (contamination). On October 12 the cerebrospinal fluid was again examined; it was clear, the albumin was 0·025 per cent., there was slight immediate reduction of Fehling and was still a *very* slight excess of lymphocytosis; cultures were sterile. A Wassermann reaction of the blood and cerebrospinal fluid was negative. The child left the hospital quite well on October 20.

The last recorded case is clearly one of lymphocytic meningitis (serous meningitis), but the cause is obscure. Tubercle as a cause of the meningitis can in this case be fairly excluded. The case does not correspond to the type of lymphocytic meningitis recorded by Gordon, in that the child rapidly recovered; there was no evidence that this child had recently had mumps or measles. Poliomyelitis as a cause seems probable, but it could not be proved.

The four cases just recorded serve as illustrative examples of the meningeal form of poliomyelitis. Clinically they differ from one another considerably. The first presented clinical symptoms which would suggest the acute onset of meningitis. The second presented features similar to those seen in tuberculous meningitis and died after fourteen days. The third was a fulminating case, passing rapidly into coma, and dying in three days. The fourth was a case in which the symptoms were slight, but the change in the cerebrospinal fluid was marked. The first rapidly recovered, leaving a paralysed leg. The second and third were proved by pathological examination to be cases of poliomyelitis, and the fourth case recovered completely from the lymphocytic meningitis, which was probably due to the poliomyelitic virus, but not proven to be so.

R. Morichau-Beauchant, Guyonnett and Corbin [102] give an account of two sisters, aged 4 and 5 respectively, the elder of whom had a definite attack of poliomyelitis accompanied by paralysis of right leg and left arm, and a week later the younger sister had meningitis from which she recovered completely.

(vi) *The "Neuritic" Form.*

Most observers are willing to accept the above forms of the disease, even when direct pathological evidence is not forthcoming; but few are willing to accept the "neuritic," for the clinical picture is so entirely different from that which takes place in other forms of poliomyelitis, and pathological evidence is almost non-existent.

If the presence and persistence of pain are taken as evidence of the "neuritis," then it may be asserted that there is no justification for the

title, since both these symptoms are well-recognized clinical manifestations of the common poliomyelitic lesions of the spinal cord.

If, however, there is an acute illness followed by weakness and wasting of the peripheral muscles, which affects all the extremities more or less symmetrically, and at the same time there is loss of sensation in the peripheral portion of the limbs with tenderness of the muscles, then it will be justifiable to regard the case as one of "toxic neuritis." If such a case occurred with a sudden onset or in association with a typical case of poliomyelitis in other members of the same family or household, it would be justifiable to assume that the same poison was the causative factor.

Some support in favour of the view that the virus of poliomyelitis can sometimes act as a direct toxin to the ganglion cells is to be obtained from the experimental poliomyelitis in monkeys made by Kling, Pettersson and Wernstedt, to which reference has already been made (p. 44). That the virus of poliomyelitis may sometimes act as a direct poison to lower motor neurons seems not improbable. It has been pointed out that mumps, like poliomyelitis, may give rise to a lymphocytic meningitis. Toxic polyneuritis may follow mumps, and the cases recorded by Joffroy [98], Revillion and Gallavardin [92] are instances of such.

Joffroy's case was that of a little girl, aged 6½, who on the eighth day of mumps had pain in the limbs and violent itching. On the twentieth day a flaccid paralysis of the four limbs set in, with complete abolition of reflexes. Cutaneous sensation was blunted. The child eventually made a complete recovery.

In the cases of toxic neuritis of unknown origin in children which have come under my observation, it has not been possible to obtain experimental evidence that the child had been, or was, suffering from the poison of poliomyelitis, and in those cases which died the pathological picture is that of a primary degeneration of the lower motor neurons, not of an infiltrative poliomyelitis. Lead, arsenic, alcohol, diphtheria and sepsis are the common cause of a toxic neuritis; mumps and syphilis rarely give rise to the typical clinical picture of a toxic neuritis, and it is only these last two which can be said to act in the two different methods: (1) by producing a lymphocytic meningitis; and (2) as a direct poison to the nerve-cell.

It has not been shown either in man or in monkeys that mumps can give rise to a perivascular lymphocytosis of the spinal cord, although it gives rise to a marked perivascular lymphocytosis in the parotid gland.

It would appear that the virus of mumps, although similar to that of poliomyelitis in many ways, has no tendency to affect the nervous system, though rarely it may do so (Gordon) [95].

Wickman discusses the question of poliomyelitic neuritis at some length, and gives illustrative cases. As evidence that poliomyelitis may produce toxic polyneuritis the following cases may be quoted.

James F., aged 16, a milk-boy. In July, 1910, he had some pain in both legs. On July 30 he was taken acutely ill, vomiting for three days; had pain in the abdomen and legs. On August 3 he could not stand, and after that the legs gradually got weaker, and after a few weeks he was absolutely unable to move them, and he could not feel below the knees. He had been in bed for two and a half months, and after the seventh week in bed his legs began to get better; the arms were never much affected. He came under my care in November, 1910. He had then weakness of the arms, feeble grasp, generalized wasting; the trunk-muscles were good; the legs were wasted below the knee; he had double foot-drop, absent knee-jerks, absent ankle-jerks. Electrical changes of the character of reaction of degeneration were present in the muscles of arms and legs. The loss of sensation had cleared up when seen in November, 1910. There was no evidence of lead or arsenic. He recovered under treatment, and was discharged well in January, 1911.

The case was obviously one of toxic neuritis. The only question was, What was the nature of the toxin? The sudden onset of symptoms during the month of August suggested the virus of poliomyelitis as the cause; the proof could only be furnished by experiments on animals, and that was not done.

A. L., aged 30, was, early in May, 1913, taken suddenly ill with weakness of the legs so that she could hardly walk when she attempted to get out of bed in the morning. She had been perfectly well the night before; she had a squint at this time. Since the onset the legs had been steadily getting worse, and when seen some four weeks after the onset there were bilateral foot-drop, tenderness of the muscles, loss of all forms of sensation below the knee, and weakness and some slight anæsthesia of the hands. The knee-jerks were absent. Complete recovery took place. The clinical picture was clearly one of toxic neuritis. What the toxin was must remain doubtful, but the sudden onset suggests the possibility of the virus of poliomyelitis as the cause.

I do not think it can at the present time be asserted that toxic polyneuritis has been *proved* to be a manifestation of the virus of poliomyelitis; but considering the fact that the virus of syphilis and mumps may give rise to the clinical picture of toxic polyneuritis, and the experimental evidence that the poliomyelitic virus does in some cases act as a direct poison to the neurons—there is reasonable ground

for suggesting that polyneuritis may sometimes be a manifestation of the virus of poliomyelitis.

The question would be solved if there was a simple specific blood reaction for poliomyelitis, and it were possible to carry out the test over a sufficient number of cases; but such has yet to be determined.

(vii) *Abortive Form.*

In this country and in London, where it may be said that poliomyelitis has never become epidemic, it is not possible to describe an abortive type of the disease. Reece, in the Stoke Rivers epidemic in Devon, described a large number of cases of indefinite illness which might possibly be cases of this nature; but the proportion of these to actual cases of paralysis was so large that it is difficult to accept them as such.

Wickman, in the Swedish epidemic of 1905, and Kling, Pettersson and Wernstedt in that of 1911, were able to recognize a considerable proportion of abortive cases as occurring in the members of households in which definite cases of poliomyelitis were present.

The picture of the abortive type as given by Wickman corresponds in general with that of the initial stages of typical poliomyelitis. The attack as a rule is acute, and accompanied by fever, headache and malaise. In some cases these symptoms are associated with others, such as rigidity in the neck, pain in the neck, back, loins and limbs, and paræsthesia, which point to infection of the nervous system.

These symptoms are not followed by paralysis. The patient usually recovers within a few days, and no trace of the disease remains, except prostration, which may be prolonged. The abortive case thus presents only symptoms of general infection, and no real localizing signs. In the abortive cases not infrequently symptoms attributable to meningeal irritation arise. More or less opisthotonus may occur. Tenderness of the extremities is common. Nausea, vomiting and diarrhœa and other gastro-intestinal symptoms have frequently been observed in association with the abortive types.

Wickman distinguishes the following varieties of the abortive type :—

(1) Cases running the course of a general infection.

(2) Cases in which signs of meningeal irritation are especially prominent.

(3) Cases accompanied by distinct tenderness.

(4) Cases with gastro-intestinal disturbances.

(2) *Relapsing Cases of Poliomyelitis.*

Reference has been made to the so-called "jump" cases of poliomyelitis in which the disease is not steadily progressive, but remains stationary for a day or two, and then rapidly advances.

Relapsing cases differ somewhat from the above in that the patient improves in the interval, and it is thought that he is going to recover. Then fresh symptoms develop, which may again clear up, and then a further relapse may occur. A very good instance of such a relapsing case with a pathological verification is recorded by Reginald Miller [100] :—

A little boy, aged 3½, was taken ill on September 14, became drowsy, unable to move. The lower limbs were completely paralysed and the neck muscles partially so ; the arms and respiratory muscles were unaffected. The boy progressed favourably till September 25th, when he became dyspnœic and cyanosed, and it was found that the intercostals and rectus abdominis were paralysed. He improved, but on October 1 a second relapse occurred, and the muscles of the left shoulder became powerless. From this date there were no fresh signs until October 17, when there developed suddenly a very marked nystagmus, lasting three to four days, gradually becoming less and less marked until the twelfth day, when it was no longer observable. During his further stay in hospital he steadily improved, and was discharged on January 3. A week later he developed broncho-pneumonia and died on January 12. The pathological examination was made by Dr. Gordon Holmes, and the specimens showed the typical appearance of a poliomyelitis, not only in the cord, but also in the medulla, pons, cerebellum, and mid-brain.

(3) *The Occurrence of Second Attacks of Poliomyelitis.*

It is well recognized that progressive muscular atrophy may occur in a patient who during early life has been the subject of poliomyelitis. A series of twenty-eight such cases is recorded by Potts [108] and they are not very rare. In eighteen the atrophy occurred in the limb previously affected ; in the remainder in some other part.

The occurrence of a second attack of poliomyelitis is very rare ; no such case has come under my observation. Eshner [88] records the case of a girl who had an attack of poliomyelitis when 25 months old, the right lower extremity being affected, and a second attack, attributed to a fall, in the hands eleven years later. Oulmont and Bandouin [105] record another case in a man, aged 60, who within a year had a second attack and died. The *post-mortem* showed changes in the anterior horn and in the muscles. A third case is recorded by Sanz [111], in a girl who had the first attack when 1 year old, affecting left leg and foot,

and the second attack at the age of 15, when the right arm and right leg were affected. Not one of these cases appears to me to be very convincing or to bear critical investigation.

(4) *Intra-uterine Poliomyelitis.*

The occurrence of poliomyelitis in the fœtus during intra-uterine life is very difficult to prove. Not a few cases come under observation in which the paralysis is stated to have been observed immediately after birth; and when the child has come under observation the clinical features closely resemble the late effects of a poliomyelitis.

Flaccid paralysis of one arm due to birth injury is far from uncommon in infants, and in most cases is probably due to injury of the roots of the brachial plexus. It has been shown by Herbert Spencer, however, that hæmorrhage into the grey matter of the spinal cord in children dying at birth or soon after delivery is not uncommon, and it is reasonable to suppose that in some of such cases which survive the paralysis may be due to hæmorrhage into the grey matter of the cord, and Boyer [84] has proved that such was the case in one instance.

The clinical evidence which is here brought forward in support of intra-uterine poliomyelitis is admittedly open to question, in that it is based on the statement of the mother of the child and not on personal observation, but the pathological evidence is complete.

The question of poliomyelitis occurring during intra-uterine life was discussed in a paper published in Brain, 1910 [81], and the case in which the diagnosis was made is there fully reported with a pathological examination proving that the condition was one of poliomyelitis.

Another case of poliomyelitis of the right arm and left leg occurring during intra-uterine life has since come under my observation, but no further pathological proof has been obtained :—

A. S., the second of three children, was born in September, 1911. The mother was not attended by a doctor. The mother states that she did not notice the weakness of the right arm until the child was 2 months old, but this child, unlike her other children, never made any attempt to move its arm. Wasting of the left leg was noticed some months later, but no attention was paid to this until the child was 18 months old, when it was found that it could not walk. The child had no acute illness from the time of birth till 2 months old, when the paralysis was first remarked. The birth was easy, and there is no evidence of injury during parturition. The child is intelligent and well nourished, has a complete flaccid palsy of the right arm, with considerable wasting, and a flaccid palsy of the left leg, also accompanied by wasting. The knee-jerk on the right side is active, on the left side absent. The child presents

the typical features of a case of poliomyelitis. The question which arises is whether this condition occurred during intra-uterine life, at birth, or subsequently. It seems impossible, considering the severity and wide extent of the lesion, that the child could have had an acute attack of poliomyelitis which should have escaped the mother's attention between birth and the second month of life. The paralysis of the right arm and the left leg is not such as one would expect from a birth injury. The case is clinically very similar to that already recorded, in which the *post-mortem* showed changes in the spinal cord characteristic of old poliomyelitis.

A third case with complete flaccid palsy of the neck muscles came under my observation in which the weakness had been present from the time of birth, the child dying when aged 2 years. No pathological examination was permitted. Further evidence on this subject is required.

(5) *Herpes Zoster in relation to Poliomyelitis.*

It is well recognized that herpes occurs not only in association with a localized paralysis in the same individual, but is also liable to be present in an epidemic form at the same time of year and in the same locality as poliomyelitis.

Garrow [124] described such a prevalence in the epidemic on the west coast of Cumberland in 1910. Brincker [120], in his report on the Stepney prevalence in 1914, states that herpes zoster was also prevalent at the same time. Many examples of herpes zoster of the forehead and face in association with ocular paralysis are on record, others of cervical herpes with facial paralysis, others of trunk or limb herpes with trunk or limb paralysis.

It is quite certain that many of these cannot be attributed to the virus of poliomyelitis ; some may be vascular, as Farquhar Buzzard [123] suggests, others are probably syphilitic, as in the case recorded by Parkes Weber [117], but there are others with an acute and sudden onset which might be attributed to poliomyelitis ; and Ramsey Hunt [127] has described acute posterior poliomyelitis of the geniculate and neighbouring ganglia.

Stanley Barnes [119] has described in considerable detail a case of right facial paralysis with herpes in the distribution of the third and fourth cervical on the same side in a man, aged 40, who recovered completely.

Alex Bruce [122] described a case of herpes of the seventh and eighth intercostal spaces, associated with weakness of the limb on the same side, with a dissociated form of anæsthesia ; he hypothesized a lesion at the base of the posterior horn which may give rise to such a group

of symptoms, involving the fibres of the pyramid as they pass from that structure to the anterior horn cells.

Frederick Taylor [128] recorded in 1895 a case of shingles followed by paralysis of the abdominal muscles in a man, aged 60. The paralysis of the muscles was first noticed about three weeks after the appearance of the rash. Three years later the paralysis was still present. He mentions similar cases recorded by Broadbent and Joffroy.

Further, Head and Campbell [126] have shown pathologically that the changes in the posterior root ganglia producing herpes are similar to those found in poliomyelitis.

Griffon [125] examined the cerebrospinal fluid in eleven cases of herpes zoster and found more or less marked lymphocytosis in all. It is a striking fact that nearly all the recorded cases of paralysis associated with herpes are in adults, and in many cases in elderly people.

In childhood the simultaneous occurrence of herpes zoster with poliomyelitis is rare, and the following is one of the few cases I have seen in childhood:—

A. R., aged 7, was taken ill with "influenza" in December, 1914. He had great pain in the right shoulder and a rash over the right side of the chest. When first seen, six weeks after the onset, there were marked weakness of the shoulder muscles and the remains of the rash over the thorax, indicated by pigmentation and slight thickening of the skin. The rash cleared up entirely, but a permanent weakness of the right shoulder remained.

A rash sometimes accompanies poliomyelitis, formed of small vesicles, widely distributed over the trunk and limbs, mostly on the former. Brown [121], in Toronto, described a small, shotty papule with a tiny inflammatory base which might or might not go on to vesiculation in association with poliomyelitis. If it did, the vesicle resembled a small chicken-pock, containing clear fluid.

Association of Herpes Zoster with a Generalized Eruption of Varicella-like Spots.—Many cases of herpes zoster associated with, or followed by, a generalized vesicular eruption have been described. These have recently been collected by Parkes Weber [118], who records a case of oculo-motor paresis and herpes associated with a generalized eruption.

It has been suggested that herpes zoster is a modified and localized form of varicella, and Johann von Bokay published nine observations in support of this view, and other writers quote similar cases. Weber discusses but does not favour this view. Whatever the pathology may be, the important clinical observations remain, that cases of herpes

zoster and a diffuse eruption like varicella occur associated with a localized paralysis of muscles in the same individual.

That some of these cases may be due to the virus of poliomyelitis is possible, but from the fact that the herpes commonly precedes the paralysis, and that the larger proportion of the cases is seen in persons of advanced years, it seems that toxic agents other than poliomyelitis must play an important part in the production of the associated symptoms. It is in cases of this nature that some simple serum test would be of such diagnostic value.

(6) *Cerebrospinal Fluid in Poliomyelitis.*

The examination of the cerebrospinal fluid in cases of poliomyelitis has yielded variable results. In some cases the fluid has been normal, in others there has been an excess of albumin, with a moderate increase of lymphocytes, in others again a very large increase of these cells.

The condition of the cerebrospinal fluid has varied not only with the time after the onset of symptoms at which the fluid was examined, but also with the nature of the case, the cases with the most marked meningeal symptoms tending to yield the largest cell count. Netter states that in the early stages of poliomyelitis the cerebrospinal fluid is definitely fibrinous and rich in cells, many of which may be polymorphonuclear.

Gay and Lucas [94] have studied the cerebrospinal fluid in monkeys during the incubation, the prodromal, and the acute stages of the disease, and in *eleven human* cases in the pre-paralytic stages. In these eleven cases the cell count varied from 55 to 580 per cubic millimetre, and the percentage of mononuclears from 75 to 100.

Peabody, Draper, and Dochez [107] examined 233 fluids from sixty-nine cases. The number of cases seen in the first week (dating from onset of symptoms and not of paralysis) was forty-three; in the second week, forty-five; in the third week, forty; in the fourth week, thirty. Four cases were seen in the pre-paralytic stage, and two in abortive cases.

The examination of the cerebrospinal fluid included pressure, number of cells per cubic millimetre, types of cell, chloride, reduction of Fehling, and globulin contents. Almost all the fluids were clear, only a few showed any opalescence. A web-like clot was seen in a small proportion of cases and in the early stages of the disease. It bore no relation to the globulin content. The pressure was usually somewhat above the normal, but the observations were unsatisfactory owing to variation due to respiratory efforts or crying. Chlorides were present in normal amount. Every fluid showed the normal reduction of Fehling solution.

The type of cell is almost always mononuclear early in the disease, but in the pre-paralytic period the polymorphonuclears may amount to 80 to 90 per cent. of the total.

The commonest type of fluid seen in the whole series is one with a normal or slightly increased cell count and a well-marked globulin reaction. Two other types are seen : (1) with a high cell count and a normal or very slight globulin reaction ; (2) a fluid with a normal or low cell count and a very marked globulin reaction. Twenty-six cases showed a slight globulin reaction and a cell count of 50 or over.

The following conclusions are deduced : fluids taken during the early days of the disease, and especially before the onset of paralysis, tend to show an increased cell count with a low or normal globulin content ; in the early stage the polymorphonuclear cells may amount to 90 per cent. of the total ; most fluids, however, show almost exclusively lymphocytic and large mononuclear cells. After the first two weeks the cell count drops to normal, and there is frequently an increase in the globulin content. A slight increase in the globulin may persist for seven weeks or longer. Analogous changes may be found in the fluid of abortive cases. All fluids examined reduced Fehling's solution.

Experience drawn from a series of cases in which the cytological examination was made by Dr. Forbes and Dr. Nabarro, at the Children's Hospital, mostly two to three weeks after the onset, would indicate that at that period the cerebrospinal fluid had in most cases returned to the normal. Even in the acute cases the increase in the number of lymphocytes has been small, as has also been the amount of albumin.

Forbes [91], in a series of thirty-three specimens from thirty cases of poliomyelitis, examined at periods of from three days to six weeks after the onset, found in twenty-four specimens the fluid was clear and free from clot. In eight trace of blood was present. In one specimen a very fine web formed on standing.

Cytological examination showed the presence of lymphocytes slightly in excess of the normal (1 to 5 per cubic millimetre), but in six specimens there was a definite increase above the normal, and in another six no cells, or only the normal few cells were present.

Netter points out that it is in the meningeal type of the disease that the cerebrospinal fluid shows most changes, and he noted that in some epidemics the meningeal type may form a considerable proportion of the cases ; he quotes instances of 50 per cent. and over.

The meningeal type must, I think, be rare in England. Of cases

seen during the year 1915 at the Children's Hospital, only two presented symptoms suggestive of meningitis. One died and the other recovered.

The diagnostic value of the examination of the cerebrospinal fluid in cases presenting symptoms of cerebrospinal disease is considerable.

In the first place it separates the cases with meningeal symptoms into two large groups: (1) Those in which the cerebrospinal fluid is turbid and contains a high percentage of polymorphonuclear cells; and (2) those in which the fluid is clear or slightly cloudy, and contains an increased percentage of cells, lymphocytic in character.

The first group is due to the presence of one of the infective organisms, meningococci, pneumococci, streptococci, influenza, *typhosus* or *coli* bacilli; the second to tubercle, syphilis, poliomyelitis, mumps, sinus—thrombosis, measles, tumour, and late cases of infective meningitis.

It has been shown that rarely a case of meningococcal meningitis may, in its early stages, give a fluid which is clear and contains but few cells; such cases are rare, and in a long series of meningococcal infection I have never come across one, although I have observed such a case in the earliest stage of a pneumococcal meningitis. As has already been stated, the reverse is also true—viz., that a case of poliomyelitis may, in its earlier stages, show a high polymorphonuclear count.

The important class to consider is the second—i.e., those in which there is an increase of the lymphocytic cells.

There can be little doubt that the condition which most frequently gives rise to a lymphocytic increase in the cerebrospinal fluid is a *tuberculous meningitis*—if tubercle bacilli are found, diagnosis is certain; but with a negative return the diagnosis is still uncertain. In tuberculous meningitis the reduction of Fehling solution is usually absent or delayed, in poliomyelitis the reaction is almost always present and immediate. The percentage of globulin is variable, but is usually higher in tuberculous meningitis.

In syphilis there is a marked lymphocytosis; but the chronicity of the case, with the high globulin content, together with the positive Wassermann, render the diagnosis clear.

The experimental work of Gordon [95] and the clinical observations of Anthony Feiling [89] on cases of mumps and on a fatal illness in children associated with acute interstitial parotitis are important in this connexion, for in both a lymphocytic meningitis may be present. Gordon took washings from the mouth and saliva from ten cases

of mumps from the first to the sixth day after onset of the disease. Having passed these through a Berkefeld filter, he injected the filtrate intra-cerebrally into ten monkeys. Four of the monkeys developed meningitic symptoms, and in one the cerebrospinal fluid was found to contain 1,500 white cells per cubic millimetre, 82 per cent. with lymphocytosis, 12 per cent. polymorphonuclears. The changes found in the nervous system were infiltration of the pia-arachnoid with lymphocytes; the perivascular infiltration characteristic of poliomyelitis was absent. There was no infiltration of the grey matter.

Gordon concludes that the experiments seem to justify the view that in a proportion of cases of mumps a virus occurs in the saliva that passes through a Berkefeld filter, and is capable of producing in the monkey, by intra-cerebral injection, a lymphocytic meningitis, together with hyperæmia of the central nervous system and acute degenerative changes in a proportion of the neurons. Furthermore, if the animal lives long enough acute interstitial parotitis may be produced. Mumps is therefore probably due to an ultra-microscopic organism.

Gordon next deals with a series of twelve cases of acute and fatal illness with cerebral symptoms in children, the cerebrospinal fluid showing a marked lymphocytosis, death taking place in twenty-four hours to twelve days.

The cerebrospinal fluid in six cases was clear and showed no bacilli; in three cases there was no increase in the number of cells, whilst in two it was 446 per cubic millimetre and 6,000 per cubic millimetre respectively. After death none of the ordinary causes of meningitis was found; the central nervous system appeared congested. In all the eleven cases in which the cerebrospinal fluid was examined *post mortem*, the cells present were found to be lymphocytic. Section of the brain and spinal cord showed no infiltration of the substance, the only change being a variable amount of chromatolysis in the cells. In one case only was a perivascular infiltration found at one point in the medulla.

In eleven of the cases foci of acute interstitial inflammation were found to be present in one or more of the salivary glands.

From five of the eleven cases monkeys were inoculated intra-cerebrally with an emulsion of pieces of the parotid gland and spinal cord passed through a Berkefeld filter. The result of these experiments was negative. The nature of the virus to which the death of these children might be attributed must remain doubtful.

Feiling [89] describes a case of lymphocytic meningitis following mumps in which the cells numbered 2,500 per cubic millimetre,

lymphocytes amounting to 96 per cent. Ten days later the number of cells had fallen to 20 per cubic millimetre, and the child recovered.

Measles again may be followed by acute cerebral symptoms, and the cerebrospinal fluid may show a high lymphocytic count.

Sinus thrombosis, cerebral abscess, infective conditions in the region of the brain (mastoid disease), and cerebral tumours, when they come in close relation to the ventricles, give rise to a lymphocytic cerebrospinal fluid.

The knowledge that a serous meningitis is present may not be of great diagnostic value, but a serous meningitis of acute onset which rapidly clears up is strongly in favour of poliomyelitis.

(7) *Blood in Poliomyelitis.*

Peabody, Draper, and Dochez [107], who examined the blood of patients with poliomyelitis, found a constant and marked leucocytosis. In several instances the count has been as high as 30,000. In only one case was there a definite leucopenia. Besides the increase in the total number of cells there has been an equally constant increase of polymorphonuclears of 10 to 20 per cent.

The visceral lesion of poliomyelitis showing the active part of phagocytosis played by the polymorphonuclear cells is perhaps sufficient cause for the polymorphonuclear increase in the circulating blood.

In view of the fact, however, that the brunt of the body's attempt at defence falls upon the lymphatic system, and that the cells which are assembled at the point of attack seem to be lymphocytes, one might be led at first to expect a lymphocytosis in the blood. On the other hand, the great destruction of lymphocytes which is evident in the visceral lesions suggests that these cells are relatively few in the circulation because they are constantly being withdrawn to meet the invasion of the virus at its various points of attack. It will require a more fundamental knowledge of the kind of reaction the body develops to this type of infecting agent before a correct explanation of the blood picture can be made. At all events, while the blood picture in poliomyelitis is perhaps not any more specific than is the spinal fluid, it is helpful. If taken in connexion with other available evidence, a leucocytosis of 15,000 to 30,000 is distinctly suggestive of the disease in question, especially if the polymorphonuclear cells are increased at the expense of the lymphocytes.

Other observers have found no change or a leucopenia, and it seems probable that in most cases the changes in the blood are inconsiderable.

Few observers have had the opportunity of examining the blood in the pre-paralytic stage of the disease such as fell to the lot of Peabody, Draper and Dochez.

Chapter VII.—Treatment.

(1) *General.*

Recognizing that poliomyelitis is an acute specific fever, having an incubation period of four to twelve days, the patient should be isolated. In hospital it is not necessary to place the patient in a separate ward, and bed isolation is sufficient to prevent the chance of infection. Personally I have never seen poliomyelitis either spread or arise in the ward, although I know of one infant who had been months in an institution develop the disease, there being no other cases in the ward, although there were chronic cases in the hospital. Peabody, Draper and Dochez isolated their patients in separate wards and dealt with them in the same way as other acute infectious diseases.

As the virus is known to exist in the nasal and buccal mucous membrane, it is well to pay careful attention to these and to any discharge therefrom, and to clean the nose and mouth two or three times a day with a 0·2 per cent. solution of permanganate of potash or chlorine water.

The acute stage is often attended by fever, sometimes by convulsions and pain, with rigidity of the neck and spine. Pain may be intense, sometimes so severe that the patient dreads the least touch of the bed or bed-clothes, or movement of the affected limbs. At times the patient may be unconscious, following a convulsion, with marked head retraction, opisthotonos, and signs of meningitis. As has been pointed out, the diagnosis in such cases depends upon the examination of the cerebrospinal fluid. Sometimes, owing to the rigidity of the back, it may be difficult, if not impossible, to do a lumbar puncture, and in order to perform this it is necessary to administer an anæsthetic. Lumbar puncture by itself often seems to relieve the most acute symptoms. It therefore is useful not only as a method of diagnosis, but also as a means of treatment.

(2) *Serum Treatment.*

It has been shown experimentally that immune serum has no power to prevent the development of the disease when injected simultaneously, or after the virus has been injected; Flexner and Amoss [132] have

shown that the intrathecal injections of an immune serum are effective when introduced in the pre-paralytic stage in delaying and preventing poliomyelitic infection in the monkey. This method of intraspinal injection of immune serum has been used with success by Netter [136] in cases of poliomyelitis of the acute ascending variety. In one case eight injections were given of from 4 c.c. to 12 c.c., obtained from a series of old cases of poliomyelitis.

The method is as follows: some 20 c.c. to 30 c.c. or more of blood are obtained by venupuncture from a patient who has passed through an attack of poliomyelitis (the length of time after the attack is not important, for it has been shown that the blood preserves its antitoxic properties for several years). The serum is separated by allowing the blood to clot and by centrifugalization. The serum is warmed to 98° F. Lumbar puncture is performed on the patient and an amount of cerebro-spinal fluid removed corresponding to that of the serum which it is proposed to inject—usually about 10 c.c. The serum is now slowly injected and the bed of the patient tilted so as to allow it to gravitate cerebral-wards. The injection can be repeated daily from three to four days or more.

There is little or no difficulty in carrying out the treatment. The difficulty is to obtain an old case of poliomyelitis who has already been tested and given a negative Wassermann reaction, and who is willing to give the necessary blood at the same time as a suitable case of acute poliomyelitis presents itself for treatment.

It is useless to carry out this treatment when the disease has already become quiescent, and the typical cases for such are either—(1) presenting symptoms of an ascending or progressive poliomyelitis, or (2) presenting meningeal symptoms, or (3) (if the diagnosis can be made) in the pre-paralytic stage.

I have on two occasions carried out the treatment: once in a baby with a lymphocytic meningitis; the child recovered, but with considerable mental defect. The second was a case of widespread and extending poliomyelitis under the care of my colleague, Dr. Still. This child, I am informed by Dr. Sidney Smith, made an almost complete recovery, but that cannot necessarily be attributed to the serum.

This method of treatment can be effective in a very limited group of cases only during the acutest stage, and special circumstances are needed for carrying it out—i.e., a suitable giver and laboratory facilities.

The possibility of employing the sera of animals has been considered. Flexner and Lewis found that the sera of horses and rabbits had no

viricidal action. Sheep's serum was slightly active and might be increased by injections of the virus, but the degree of activity appears to have been small.

(3) *Drugs.*

The acute pain associated with the disease can to a large extent be relieved by careful support of the limbs and of the patient, and of the arrangement of the bed. Aceto-salicylic acid is the drug which in my experience gives most relief; other coal-tar derivatives are of value, but in some cases morphia is needed. The administration of hexamine has been advocated on experimental grounds, for it has been shown that it passes into the cerebrospinal fluid, and that in animals it tends to delay, if it does not prevent, infection of the spinal cord by pathogenic organisms. It should be administered in large doses, 10 gr. every four hours to young children. There is no doubt that hexamine reaches the spinal fluid, but there is some doubt that it is present in that fluid in the active form of formaldehyde or that it has any beneficial effect. The only disadvantage in the administration of this drug is that it occasionally gives rise to hæmaturia.

(4) *Rest, Posture, Re-education.*

There can be no doubt that rest is the most important method of treatment. The too early movement may in some cases restart the disease which has become quiescent, and relapses have been produced in this way. A child with an acute attack of poliomyelitis should be kept absolutely at rest in bed for at least three weeks; the length of time necessarily depends on the severity, but even in the slightest cases movement before this time is inadvisable. Though bed may give rest to the body generally, it does not necessarily afford the complete physiological rest required for recovery of a muscle, and hence it is essential to consider the principles on which such rest can be secured. Sherrington [138] has shown that the normal skeletal muscle is possessed of a degree of tension or tone, and that there is a reciprocal innervation of muscles, so that when the flexor contracts there is an active relaxation or inhibition of tone in the extensors. The tone of the muscles is largely dependent on afferent impulses. If the extensors are paralysed and the limb lies in the flexed position, there is a tendency for the extensor to become stretched, whilst the flexor becomes more contracted; but not only is there an actual stretching of the paralysed muscle, but there is in all probability an active inhibition giving rise to a further loss of tone. The anatomist, William Mackenzie, expresses

the same in somewhat different language. The muscle adjustments are so fine that immediately the nerve-cell governing the action of the flexor is affected, the extensor opponent begins to over-act, and this over-action must be prevented for the following reasons: (1) It does not allow complete rest of the affected anterior horn-cell; (2) by over-stretching the affected muscle it interferes with its recovery. Robert Jones [134] expresses the same facts by a mechanical metaphor, saying: "The whole reflex apparatus by which the spinal nerve-cell and muscle react on each other to their mutual benefit is put out of gear." And he insists on relaxation of the paralysed muscle; but as William Mackenzie [135] points out, relaxation is only the beginning of treatment, and more than this is required, and that is re-education of the paralysed muscle. All are agreed that a stretched muscle is at a disadvantage and will not recover its power until relaxed.

Posture.—Posture is therefore the great factor in securing physiological rest to a muscle, and it is important to consider what is the *zero position* of any given muscle. Mackenzie defines the zero position as the position of anatomical rest in which the individual muscle itself is relaxed, and both its own action and that of its opponent's prevented. Sherrington has shown that the distribution of tonus is arranged on a plan of strict co-ordination, and that reflex tonus embraces those movements which counteract the effect of gravity, and that postural contraction can be maintained for long periods without fatigue. A position which can be maintained without fatigue must be the position of rest.

Application of the Principles of Rest, Posture, and Re-education in the Treatment of Paralysed Muscles.

Rest, posture and re-education are the important methods of treatment. Various methods have been adopted for keeping the paralysed muscles at rest and in a state of "relaxation." Simple rest in bed is regarded by some as sufficient. Others place the limbs between sandbags, so as to prevent movement and misplacement of the limb. Others place a board at the bottom of the bed, which is often effective in keeping the foot in the dorsi-flexed position. Various splints of metal and other material have been used. Some medical men have advocated placing the patient or the limb into a plaster of Paris mould, so that no movement is possible. Robert Jones insists that the paralysed muscles must be placed into the position of complete relaxation, and that any deviation from this position, even momentary, is harmful. Success

has, and will, attend all these methods, but they all have the same disadvantage that they tend to immobilize the patient for the period of many months, and give the child but little chance of physiological action and re-education of the muscles, which may have been greatly or slightly affected.

Plaster-of-Paris.—The use of plaster-of-Paris as a means of support is easy, and in selected cases of poliomyelitis is most valuable. In some the limb can be placed into plaster-of-Paris in the ordinary way; in others, a removable plaster-of-Paris splint can be made so that the limb is kept in the zero position until recovery has taken place, or until a more permanent splint is made, and treatment by massage, passive and resistance movements can be carried out in the meanwhile.

Splints.—The practical application of the above principles has been carried out by the following method: The paralysed limb or limbs are placed in a light celluloid splint accurately fitted to the limbs as soon as it is possible to make the cast after the onset of the disease. These splints were first made by M. Calot [131] in France, and introduced into this country by Gauvain [133], who employed them extensively in the treatment of tuberculous joints, and most kindly instructed me in their use [130].

It is not my intention to enter into any detail here as to their construction, but seeing that the splint is to serve in most cases not only for keeping the muscles at rest, but also as a support in walking, it is essential that the position of the limb should be such that progression is possible. The splint is moulded on a plaster-of-Paris cast of the limb, and it is the making of this cast which is important, for the limb must be in the *zero position*, or in other words, the position normally assumed to counteract the effect of gravity when the patient is in the erect position. That position, so far as the legs are concerned, is one of *slight flexion of the knee* with the *foot at right angles*, or at an angle slightly greater than a right angle to the tibia (fig. 36).

The advantages of this form of splint are: (1) That they maintain the muscles constantly in a position of rest, for they can be worn day and night; (2) they do not immobilize the patient, so that walking exercise can be carried out without the liability to produce deformity or stretching of the muscle; (3) they are easily removed and replaced, so that other methods of treatment can be carried out; (4) no special boots or shoes are required (fig. 37).

The aim of treatment has been to keep the limbs in a normal position and free from deformity whilst recovery is taking place, and

FIG. 36.—Photo of child with flaccid paralysis of both legs in celluloid splints. Note that the splint is taken sufficiently high so that the weight of the body is supported on the tuber ischii, the knee is slightly flexed and the foot is at right angles to the tibia.

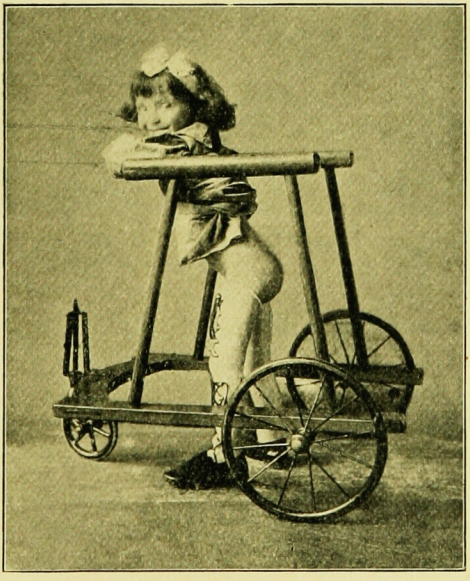


FIG. 37.—Photo of same child in walking machine. The early stage of the re-education of the child in walking.

the result has to a great extent been attained. In the legs with paralysis of the muscles of the thigh and below the knees no great difficulty arises. All the mal-position of the foot and knee can be prevented. It is somewhat difficult to prevent the outward rotation and abduction of the leg below the knee in those cases in which the biceps femoris is relatively good compared to its antagonists. So long as the child has remained in the hospital no deformity has arisen, but under home conditions in which the splint is left off and massage and

FIG. 38.—Photo of same child at a later stage, when the child can walk easily and rapidly with the machine.

educative movements not maintained, the deformity readily occurs and is not easily corrected. The flexor and extensor muscles of the hip are, however, the most difficult to keep in a position of relaxation. So long as the child is lying in bed the tendency for the flexors of the hip to contract can be prevented, but if the child is allowed to sit up the flexors tend to assume a contracted position, with the result that the hip is flexed on the pelvis (fig. 29, p. 58). In such cases it is best to allow the child only to assume the erect or lying position. The erect position can usually be assumed by means of a walking machine (fig. 38), whereby

the child supports the weight of the trunk on the hands and allows the limbs to swing. Such a position tends to re-educate and bring into function not only the flexor and extensor movements of the thigh, but also all the muscles of back and abdomen. Careful attention to the extensors of the legs, with regular massage and movements, will to some extent prevent this contraction, but in severe cases, in which the extensors are completely paralysed and the flexors but little affected, the flexors come into action, and when the child attempts to assume the erect position lordosis is produced. I am rather of opinion that in these cases it is best to put the flexors out of action by division, and if this be done early it gives the opposing extensor a greater chance of recovery and prevents any displacement of the hip-joint, which is likely to occur if the contracture is of long duration.

A still more difficult condition to deal with is that of paralysis of the flexor of the hip with good power remaining in the extensor. This is fortunately a very rare manifestation. It is possible to place the child in a fixed position with the knees and thighs flexed, and this has been done and maintained for some months; but a few days after the child is taken out of plaster the position of hyper-extension is again assumed. Allusion to this form of deformity has already been made in the clinical section of these lectures, and in the case referred to treatment was completely unsuccessful (fig. 30, p. 58).

Abdominal and back muscles.—If these muscles are seriously involved, standing and walking are almost impossible. On the other hand, there is no exercise which is so effectual in re-educating them as that of attempting to balance and assume the erect position. Deformity can be prevented by the recumbent position and by extension, but should the affection of the muscles be severe the child will need artificial support to prevent deformity when it assumes the erect position.

Walking exercise and the erect position.—When once the legs are splinted it is possible to get the patient into the erect position, and such allows of the physiological use of the back, trunk and pelvic muscles. Such walking exercises are carried out by the use of a walking machine, which supports the child both physically and morally, for it is important to give the child complete confidence in itself (figs. 37, 38, 39).

Arms.—The most common form of paralysis of the arm is a paralysis of the deltoid, biceps and shoulder muscles, while the forearm remains relatively good. In order to relax the deltoid the arm must be abducted from the thorax, and it is usual to place the hand behind the head so as to secure this. I have adopted two methods in dealing with these cases:

(1) To make a celluloid splint which will hold the arm abducted and flexed (figs. 40 and 41); (2) a Fairbank splint, which keeps the arm in this position (fig. 42). The disadvantage of the former is that it is difficult to make, and the angle of the abduction cannot be altered. The advantages of the latter are that it is easy and cheap to make, and is readily adjusted to any angle required. The arm should be kept in that

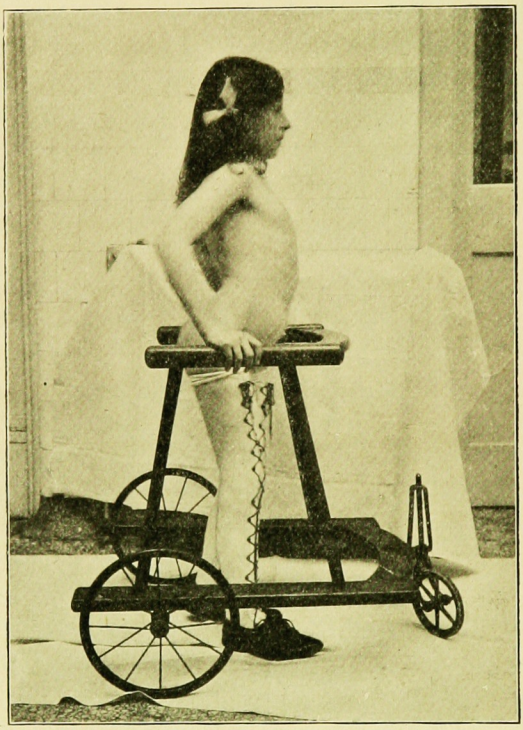


FIG. 39.—Photo of child with poliomyelitis learning to walk. Considerable lordosis has been produced owing to the long standing contraction of the flexor of the hips.

position day and night for at least twelve months. If at the end of that period no improvement has taken place it is improbable that any recovery will occur, and the arms can be placed in the flexed position at the side, so that the hand may be of greater service.

Neck.—The isolated paralysis of muscles of the neck is a somewhat rare manifestation. A child with this affection is quite unable to walk, owing to the inability to maintain the balance. A collar which will hold the head in the erect position not only places the paralysed muscles at rest in the zero position, but also prevents the head being jerked

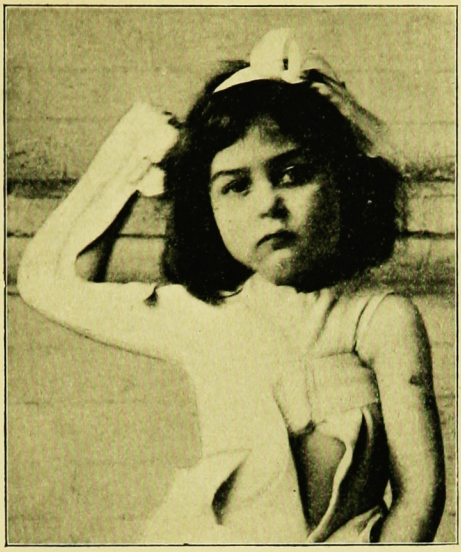


FIG. 40.—Child with paralysis of the deltoid and biceps muscles in celluloid splint. The splints tend to keep these muscles relaxed and prevents the over-action and contraction of the latissimus dorsi and pectoral muscles.

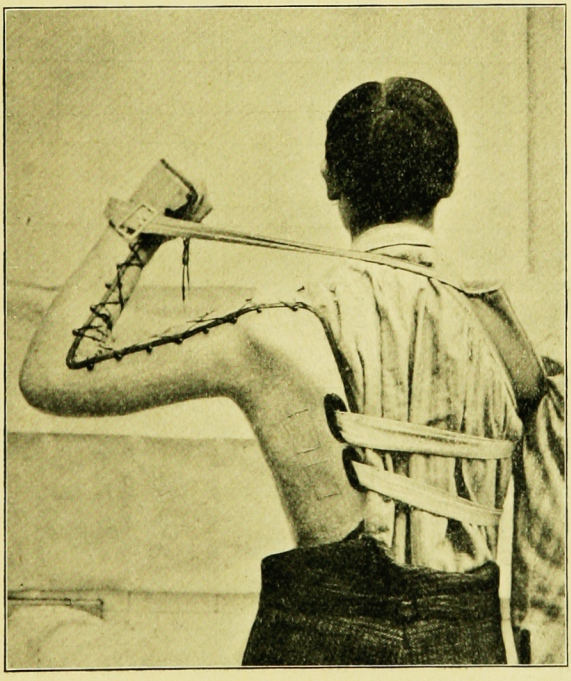


FIG. 41.—Man with poliomyelitis of the shoulder muscles of the left arm. The splint has an additional support from a strap and band round the right shoulder.

either forward or backwards, thus throwing the child to the ground (fig. 43).

The above are simply instances of the application of the principles that the paralysed muscle must be placed in the position of rest. Almost every case varies in the muscles paralysed, and needs individual thought as to the position in which the limb should be placed. If, however, medical men will adopt the practice of placing the limb in a splint in a position of rest *at an early stage of the disease*, not only will the recovery of the muscles be more complete, but the greater portion of the deformities which one now sees as a result of poliomyelitis will be prevented.

Re-education of movements and muscles.—The re-education of the paralysed muscle is of great importance. With a severely paralysed muscle it is essential in early stages to place the limb in such a position that the load on the muscle is at its minimum; for the sake of example, with a paralysed biceps of the arm the upper arm must be in the horizontal position, as it is when the patient is recumbent, the forearm in the vertical position at right angles. Only a very small force is now required to overcome gravity and flex the arm. The angle is slowly increased and graduated to the power of the muscle as it slowly recovers. A bath is an excellent place to practise the re-education of muscles, for the weight of the limb is supported and ranges of movement are possible which are impossible without the support of the water. Education will gradually increase these movements.

(5) *Massage.*

In massage—and under this heading I include all active and passive and re-education movements—we have most valuable methods of maintaining the nutrition of the muscles and assisting recovery whilst regeneration of the damaged neurons is taking place. Friction and warmth to the skin stimulate, and are of great service in maintaining the circulation.

Warm baths and douches.—Warm baths and douches have the same effect, and are of service in relieving pain and allowing of movement in an otherwise painful joint.

(6) *Electricity.*

All forms of electricity have been employed in dealing with cases of poliomyelitis: some may be of service, others are useless, others again are harmful. It is probable that the galvanic current is of service

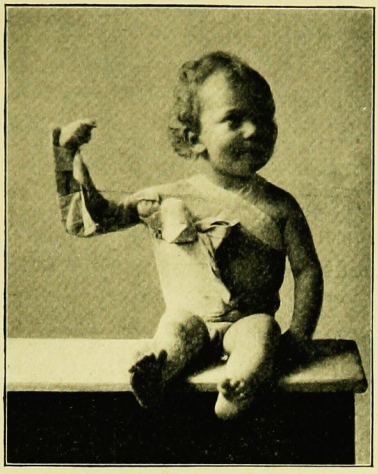


FIG. 42.—Child with poliomyelitis of the right deltoid and bicep in Fairbank splint. The advantage of this splint over the celluloid is that the angles can be easily adjusted.

FIG. 43.—Boy with flaccid paralysis of neck muscles in celluloid collar.

in stimulating paralysed muscles to contract, but the current, when sufficiently strong to cause a paralysed muscle to contract, gives considerable pain to children and is ill borne, and the advantages gained by no means compensate for the emotional disturbance produced.

Faradism and the alternating currents may be said in most cases to be directly harmful. They cause the active contraction of unparalysed muscles, whilst the paralysed muscles do not react; thus the paralysed muscles are stretched.

The skin stimulation to which other forms of electricity give rise may be of some benefit.

(7) *Other Methods of Treatment.*

It is not my purpose to deal with the later stages of paralyses which require some mechanical replacement of and support for the paralysed muscle, nor with the surgical aspect of the treatment of the late effects of poliomyelitis by tendon lengthening, tendon transplantation, tendon fixation, artificial ligaments, nerve-grafting, arthrodesis, and the like; but I am convinced that if the line of treatment above advocated is extensively adopted, recovery of power in the muscle will be greater and a large proportion of the deformities which are now seen in cases of poliomyelitis will be prevented.

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APPENDIX.

Method of making Celluloid Splints.

The method of making celluloid splints is so simple that it can be carried out by anyone gifted with a little manual dexterity.

Celluloid splints have a triple object:—

(1) Of keeping the muscle at rest in the "zero" position.

(2) Of preventing deformity.

(3) Of enabling the patient to walk and thus applying a physiological stimulus to aid the recovery of the affected muscles.

In making these splints there are three processes involved:—

(1) The taking of the "negative" cast of the patient's limb.

(2) The making of the "positive" cast from the negative.

(3) The moulding of the splint on to the "positive."

(1) For taking the "negative" the following articles are required: A strip of lead, 1 in. wide and 2 ft. to 3 ft. long; some plasticine, some oil, two strong knives, one with a convex cutting edge and the other concave with a sharp point, and some plaster-of-Paris bandages. These bandages should be made of book-muslin, 4½ in. to 6 in. wide and 4 yards to 6 yards in length; they should be loosely wound and not too heavily loaded with plaster.

For taking a cast of the leg the limb is oiled, the strip of lead adjusted to the anterior surface and small disks of plasticine applied over both malleoli so as to give more room and prevent the splint pressing on these prominent bony parts. The leg is now held in the position required; *there should always be slight flexion of the knee, and the foot held carefully at right angles to the tibia.* It is better to err on the side of putting the foot into the position of equinus rather than calcaneus, for with any hyperextension of the knee and over-dorsiflexion of the foot the patient is uncomfortable and cannot walk.

It is useless to take a cast or make a splint for a leg which cannot be placed in the normal or approximately normal position assumed on standing.

In most cases in which the leg is affected it is necessary to take the cast right up to the tuber ischii behind, the ramus of the pubes on the

inner side, and the great trochanter on the outer side. The bandages should be loosely applied and gently moulded to the shape of the limb after application.

It is well to take each bandage continuously up from the foot to the thigh. A few extra turns are needed over the ankle and knee, and if this is done there is little liability for the cast to crack transversely when taken off the limb. For a child aged 6 to 8, about four or five bandages are required. When the plaster is sufficiently set, which usually takes place in about three to five minutes, a cut is made down the anterior aspect of the leg on to the surface of the lead with the cutting edge of the convex knife, and when the bandages have been divided as far as possible, the knife with the sharp point is used, and with this it is possible to feel and divide all the remaining threads.

The incision must be complete and all fine threads must be divided, for unless this is done the cast is liable to be spoilt by portions of the bandage being dragged out of place. The cut edges of the plaster are now separated sufficiently to allow the lead and the leg to be removed.

This is best effected by catching hold of the toes and dragging them forward, whilst an assistant separates the edges of the cast and pushes it backwards. When the cast has been removed the cut edges are carefully approximated and a single layer of plaster-of-Paris bandage is wound round the cast, the toe end being completely covered in. The negative cast is now complete and allowed to dry.

For the arm in which there is paralysis of the deltoid and biceps, the arm should be raised at right angles to the trunk, and bent at the elbow. The position can be maintained by a Fairbank or celluloid splint. The former is cheaper and more easily made than the latter.

For the thorax exactly the same procedure is adopted, but it is well to suspend the patient so as to get the spine as straight as possible; if this is not feasible it is usually possible to get a good cast of the trunk with the head supported by a nurse.

Two strips of lead are required—(*a*) from the chin to the pubes; (*b*) from the side of the neck to the shoulder.

It is well to place a large pad of wool over the upper part of the abdomen to allow for respiratory movements.

It is important to take the cast well down over the crests of the ilia and to get a good impression of these, for it is largely from these points that the spine obtains its support through the jacket. Should it be impossible to secure the cast in the suspended or standing position it can always be obtained with the child lying on an open frame, from

the ends of which a broad piece of linen or gauze is stretched, the gauze or linen being included in the cast.

For the neck, the head should be carefully supported in the position in which the muscles normally keep the head when standing. The hair should be oiled. A strip of lead is placed over the head and brought down over the right ear to the right shoulder. The plaster cast is taken well up over the occipital region and round the chin, for it is from these points that the chief supports are obtained above, and well down over the thorax and back, so as to afford a wide base below for the support of the weight of the head.

It is well to cut a window out of the celluloid collar over the larynx, as any pressure on this region gives rise to a feeling of discomfort.

(2) The making of the "positive cast" is carried out in the usual way. The inner side of the negative cast is oiled, plaster-of-Paris mixture poured into this and a bamboo cane placed down the centre. After the plaster has set, an incision is made down the anterior surface, the "negative" peeled off, and the "positive" remains. Any projection which may be present may need a little smoothing down.

(3) For making the splint the following articles are required: (*a*) stockinet, (*b*) book-muslin, (*c*) solution of celluloid in acetone (Gauvain uses the following solution: 11 oz. of celluloid dissolved in 160 oz. of acetone, to which is added a solution of 3 oz. of anhydrous calcium chloride or 6 oz. of the crystalline calcium chloride dissolved in 2 oz. of boiling water. This solution, whilst still near boiling temperature, should be added gradually by stirring to the celluloid solution and well shaken up; the resulting solution is opaque and deposits on standing a sediment which must be stirred up before use), (*d*) aeroplane or celluloid varnish (cellulose triacetate 1 part, acetone 5 parts), (*e*) some leather or braid for binding the splints, and (*f*) some boot-hooks.

Three layers of stockinet are first drawn over the cast. On the third layer is painted a coat of celluloid solution. A layer of book-muslin is now applied down the back of the splint and a coat of celluloid solution painted on; another stockinet layer is drawn on and a further coat of celluloid solution and a layer of book-muslin applied; this is continued until a sufficient thickness is reached. Six to seven layers of stockinet are sufficient for the front of the splint, but the back must have twelve to eighteen layers, depending upon the size of the limb and weight of patient, the extra layers consisting of book-muslin. The knee and ankle also require some extra layers of muslin.

Each coat of celluloid must be allowed to dry to a certain extent (fifteen minutes is usually enough in dry weather) before the next is applied. After the last has been laid on, a final coat of celluloid varnish is applied. When this has dried, an incision is made down the front of the splint. This allows the "positive" to be taken from the interior of the splint. The innermost layer of stockinet is removed and a coat of celluloid varnish applied to the inner side of the splint.

The splint is now fitted to the patient. If the cast has been well made, it usually fits perfectly. Some small amount of the splint may need to be cut away about the knee and ankle, so as to allow of easy application and removal. The splint after being bound with leather or braid and boot-hooks inserted, is ready for wear.

In early and acute cases, when the patient is still in bed, the splint is applied and worn both day and night, being removed only for massage, active and passive movements twice a day.

A thin silk stocking or stockinet should be worn under the splint, but it is inadvisable for the patient to wear a thick one, as its thickness displaces the limb and the splint will no longer fit well. If the splint seems to cause pressure at any point, it should be stretched and manipulated so as to relieve the pressure. It is inadvisable to put wool or leather inside the splint to avoid pressure; if pressure on the malleoli cannot be relieved by manipulation of the splint, additional space can be obtained by removing some layers of gauze from the inner side, or if this is insufficient a hole can be cut in this region and the edges pared off.

At the end of the first month after the onset of the disease, it is usually possible to get the patient up, and the splint enables such patients to walk without any liability to the production of deformity.

Over the splint the patient wears a stocking, an india-rubber shoe, an ordinary boot or clog, the variation in the footgear depending on the environment of the patient.

The earlier attempts at walking must be very carefully performed, but with the aid of a walking apparatus the patient rapidly gains strength, and many cases, which from the extent of the paralysis would seem almost hopeless, are soon able to walk alone.

Almost any paralysis of the lower limbs, however severe, can be supported with celluloid splints, whether child or adult, and so long as the psoas and iliac group of muscles and the glutei remain good, it is possible to get the patient to walk fairly well.

Cases in which abdominal and back muscles are affected are those

which are most difficult to deal with, and in any case in which these are considerably affected support can only be obtained by a spinal jacket.

If the paralysis is limited to muscles below the knee a splint as far as the knee is all that is required. In cases in which the arm is affected it is generally the proximal muscles which are most affected, and the deltoid, biceps, triceps suffer most. In such a case the arm should be placed in the abducted position and flexed at the elbow.

The arm should be placed in this position as soon after the onset of the paralysis as possible, and should be maintained in that position for six or twelve months whilst recovery of the deltoid is taking place, the splint being worn day and night, and only removed for purposes of washing and massage.

If the above line of treatment is properly carried out many cases by the end of the first six months have so far recovered that no further splint is required; in others a simple one to support a single group of muscles is all that is needed. Nearly all the deformities which are the chief cause of the incapacity can be prevented.